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AI-Enabled Dual-Use Systems in LEO Satellites: The Case Study of IRIDE Constellation

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Abstract

The thesis analyzes the evolution of EO satellite systems in LEO and the impact that new AI systems are having on the growth of their dual-use nature. Through the specific analysis of the case study of the Italian IRIDE constellation, the aim is to understand how AI-enabled systems have been essential in the development of the space sector and how they integrate along the three operational segments (upstream, downstream, service segment). The vision of the paper on the functions of IRIDE goes beyond the merely scientific aspect of the constellation, providing a point of view on the potential role that it could assume in crisis scenarios. IRIDE will be placed within the broader framework of the "new space order" and compared with foreign models to highlight, according to different governance systems, the possible different conformations that constellations of EO can assume in relation to data management and their control regime. The paper shows how possible AI applications within the various segments of IRIDE could increase possible ambiguities related to the dual-use nature of the constellation and possible tensions arising from European regulatory constraints (AI Act and GDPR). In a diachronic scenario, moreover, the analysis aims to clarify how the dual-use nature of the constellation may collide with the nature of the PNRR funds from which it is financed, highlighting the political-institutional difficulties in recognizing dual-use spatial structures.

Key words: LEO, AI, EO, dual-use, new space order, data governance, space diplomacy, militarization of space, AI Act, GDPR, PNRR.

Contents

List of Figures

List of Tables

Notation

AI	-	Artificial Intelligence
AOCS	-	Attitude and Orbit Control System
ASAT	-	Anti-Satellite
ASI	-	Agenzia Spaziale Italiana
CAGR	-	Compound Annual Growth Rate
CHEOS	-	China High-resolution Earth Observation System
CNSA	-	China National Space Administration
CSIS	-	Center for Strategic and International Studies
DL	-	Deep Learning
DTIC	-	Defense Technical Information Center
ENISA	-	European Union Agency for Cybersecurity
EO	-	Earth Observation
EOCL	-	Electro-Optical Commercial Layer
ESA	-	European Space Agency
ESPI	-	European Space Policy Institute
FOS	-	Flight Operation Segment
GDPR	-	General Data Protection Regulation
GEO	-	Geostationary Orbit
GLONASS	-	Global Navigation Satellite System
GNC	-	Guidance, Navigation and Control
GNSS	-	Global Navigation Satellite System
GOFAI	-	Good Old-Fashioned Artificial Intelligence
GPAI	-	General-Purpose Artificial Intelligence
GPS	-	Global Positioning System
GSO	-	Geosynchronous Orbit
HEO	-	Hawk for Earth Observation
IEEE	-	Institute of Electrical and Electronics Engineers
INMARSAT	-	International Maritime Satellite

INTELSAT	-	International Telecommunications Satellite Organization
IPL-11	-	Information Processing Language
ISR	-	Intelligence, Surveillance and Reconnaissance
ISRO	-	Indian Space Research Organisation
ISS	-	International Space Station
LEO	-	Low Earth Orbit
MEO	-	Medium Earth Orbit
ML	-	Machine Learning
MIO	-	Medium Inclination Orbit
NASA	-	National Aeronautics and Space Administration
NIMBUS	-	New Italian Micro Bus
NRO	-	National Reconnaissance Office
OECD	-	Organisation for Economic Co-operation and Development
OST	-	Outer Space Treaty
PA	-	Precision Agriculture
PL	-	Payload
PNRR	-	Piano Nazionale di Ripresa e Resilienza
PRISMA	-	PRecursore IperSpettrale della Missione Applicativa
RL	-	Reinforcement Learning
RS	-	Remote Sensing
SAR	-	Synthetic Aperture Radar
SSA	-	Space Situational Awareness
SSO	-	Sun-Synchronous Orbit
STM	-	Space Traffic Management
TLC	-	Telecommunications
TOA	-	Top of Atmosphere
UNOOSA	-	United Nations Office for Outer Space Affairs
VNIR	-	Visible and Near InfraRed
VHR	-	Very High Resolution

Introduction

Since the last two decades, the increase in the number of actors – public and private – active in the Outer Space sector, exemplifies the growing interest and the enormous possible advantages that the space domain presents nowadays. If the launch of the first *Sputnik* satellite in 1957 marked the beginning of the Space Race, where the two superpowers of the time, the United States of America and the Soviet Union, found a further field of confrontation, thanks to the progress of scientific research and the adoption of crucial new technologies, human knowledge of Outer Space has reached previously unimaginable heights. From an environment mainly associated with fields of domination such as astronomy and international cooperation, space has also taken on a strategic value over time, where economic interests, technological competition and competition for a better geopolitical positioning are intertwined. Not only that: today the capabilities offered by space infrastructures translate into an advantageous position also in the military field. In the context of the Russian-Ukrainian conflict, the cyber-attack attributed to Russia against the Viasat network gives an image of how space infrastructures have become priority targets even in war scenarios.

In this context, Low *Earth Orbit* (LEO) has emerged as the most dynamic and functional area for a multitude of space activities. Thanks to the reduction in the cost of access to space, linked to the ever-increasing miniaturization of satellites, the development of new constellations makes low orbit increasingly congested, through the proliferation of infrastructures dedicated to Earth Observation (EO) and Telecommunication (TLC), which have become crucial elements in the daily life and essential functions of states. In addition, the integration of Artificial Intelligence (AI) systems along the entire space value chain has become a tool that is not only useful but also decisive for the success of new space missions. Thanks to their peculiar structure, AI systems are perfectly integrated within *end-to-end infrastructures* in the three segments of interest: the *upstream*, the *downstream* and the *segment service*. The ability to self-correct the flight course of satellites or shuttles, the monitoring of the various Payloads (PL) and the automation of the analysis processes of the data collected, are just some of the services made possible by the adoption of AI-enabled systems. However, when applied in critical contexts, such as the military scenarios just described, AI systems can amplify the *dual-use* nature of contemporary space technologies. Almost all satellite systems, in particular those relating to the EO sector, will be analyzed, although designed for *civil-first* purposes, they are tools that can be used in security and defense fields. In other words, the ability to acquire high-resolution images through a high frequency of revisits, can be of support in the optimal management of agricultural land

and, at the same time, be crucial for the surveillance of the national borders of a state. In this sense, AI increases this ambivalence because it reduces decision-making times, making the detection, classification and correlation of the acquired data more effective.

Starting from this framework, this paper will try to address the issue of "AI-enabled dual-use systems" in LEO satellites taking as a case study the new Italian "constellation of constellations" IRIDE. The new Italian project, born in the midst of the Covid-19 pandemic context, is presented as a national infrastructure for the EO sector that will try to increase Italy's positioning in the space sector. Its 8 application segments make the new Italian constellation a strategic dual-use infrastructure capable of placing itself in the global trend of new high-resolution systems, capable of covering a multitude of essential services both for the Public Administration and for the Italian industrial supply chain. As an end-to-end system, its services are not limited to image acquisition but, combined with the possible integration of AI, accentuates the possible ambiguities typical of contemporary dual-use systems.

For this reason, the paper will try to provide answers to the following questions: what ambiguities can arise starting from the possible integration of AI systems within end-to-end infrastructures such as IRIDE? How does it fit into the European regulatory framework? In particular, what constraints could emerge from the European (EU) *AI Act* and *GDPR* Regulations? What advantages, and what disadvantages, could the dual-use nature of the constellation cause? To conclude, a specific analysis will be reserved on the nature of the funding funds of the IRIDE project (PNRR) and a possible divergence between the purpose of the work and their target application.

The thesis is structured in 4 chapters. Through a qualitative methodology, IRIDE is placed in the international framework of the current EO structures, while a comparative analysis with two of the main reference structures, one in the United States and one in China, will support to highlight how different governance models can produce different political effects, both in the management of the data acquired and in their actual use. Chapter 1 introduces two fundamental aspects: on the one hand, through a classification process, the possible different conformations of satellites in orbit will be listed and, on the other, the evolution of AI in space activities and the dual-use concept will be introduced. Chapter 2 explores the IRIDE case, reconstructing the various phases of the project, its technological architecture (to which Appendix A is dedicated) and some of the potential dual-use ambiguities. Chapter 3 tries to place IRIDE in the *new space order*, through the analysis of today's main public actors (USA, China, Russia, India, Europe), the ambitions and the historical role of Italy in the space context and the comparison of IRIDE with foreign constellations. Finally, Chapter 4 will

try to provide answers to the questions just introduced, going through the various issues of European constraints on the adoption of AI, possible risks in the management of personal data and ambiguities arising from the PNRR-IRIDE link.

The adoption of AI-enabled systems within the international scenario of EO infrastructures in LEO represents one of the fundamental tools in terms of technological efficiency but brings with it a change with potential geopolitical effects. Analyzing the new Italian constellation IRIDE under this new lens allows us to understand how space activities have become an integral part of geopolitical dynamics on Earth.

Chapter 1

Artificial Intelligence and Dual-Use Satellites in Outer Space

The integration of AI systems into dual-use satellite infrastructures represents a technological and strategic transformation in contemporary space activities. AI-enabled satellites serve simultaneously civilian and military objectives, raising questions of governance, operational ambiguity, and geopolitical stability that this thesis addresses through the case study of Italy's IRIDE constellation. Dual-use satellites collected every second an incredible amount of data that need to be processed as fast as possible to let people be able to complete normal action inside a common day, like surfing on the web or let our new car park itself by its own. And while AI systems facilitate and improve the actions of dual-use satellites, like a self-sustaining system, new forms of AI will be required to make the results and data collected more and more effective. But where these satellites operate and why? How AI systems can be applied? *Machine Learning* (ML) and *Deep Learning* (DL) are just a few examples of applications of AI in the outer space. Although we are now living what just few decades ago were defined as a truly "futuristic scenario", new generation of risks and threats have pushed the major spacefaring players to be worried and concerned. AI-enabled systems are now considered as potential sources of both strategic and political instability, especially when they are adopted inside dual-use satellites that serve at the same time, civilian and military objectives.

1.1 Artificial Intelligence in Space Activities

The interest in AI within the space community has deep roots that date back to the last century, when both domains – AI and space technologies – went through the various phases that led to the establishment of their current form. From the very beginning, in fact, both domains have shared an interdisciplinary growth path, capable of developing the two sectors towards previously unthinkable universes. Although in different ways, both fields of research can be considered main protagonists within the "Fourth Industrial Revolution", an epochal rupture that redefines the human being in his relationship with technology, society and the environment (Park, 2016), distinct from the previous ones not only for the technologies involved, but in particular for the speed and pervasiveness that it

exerts on all social and economic fields. Speed and transversal pervasiveness, as we will see, represent the essential characteristics elements in the processes of application of AI in space activities. The advent of AI has dramatically improved the various phases of space missions, starting from the design and planning phase to in-orbit operation, through the application of algorithms capable of autonomously identifying the most promising combinations of parameters, automatically optimizing them to meet mission requirements and budget limitations (ASI, 2024). These are just a few examples of AI application processes within space activities. However, it is not currently possible to draw a boundary on their applicability: as pointed out in the study by Rußwurm et al. (2020), "the nature of the space and satellite industry presents a quintessential use-case for AI. Essentially, virtually all space activities and ventures constitute fertile ground ripe for employing AI" (Rußwurm et al., 2020). It is precisely the singularity of the nature of outer space that considers the specificity of the forms of application of AI and its distinction from the most common use in terrestrial environments. Below is a list of some of the distinctions mentioned above:

1. **Harsh conditions of space**. Space is an unknown, hostile, unexplored environment, currently uninhabitable for human beings without the aid of massive technological support that largely refers to processes related to the use of AI. In this context, AI-based technologies are fundamental for decision-making operations, which must be adaptive, resilient, fast and versatile to continuous threats in space.

2. **Upstream and downstream AI impact on space sector.** Increasingly, the contribution of AI on space activities will have a transversal impact not only in the segment of in-orbit operations – Upstream – but more generally on the entire process of the operational cycle: from the testing phase for the launch of new objects, to the analysis of the performance of satellites in orbit. Indirectly, therefore, AI processes are applied to the entire Supply Chain sector related to space activities. Its applications are not limited to the ground: on board payloads, new intelligent algorithms are integrated to improve in-orbit operations. At the same time, the downstream sector (with particular reference to the TLC and EO sectors) is also benefiting greatly from the implementation of AI. Among its many uses, it is used to automate and classify images captured by satellites, acts as a support to detect any anomalies, performs predictive analysis of phenomena and optimizes data management, improving the efficiency of commercial applications and geospatial services.

3. **Autonomy decisions of space objects.** As already mentioned, using AI programs a satellite may be able to adjust its orbital course depending on the autonomous surveys of the surrounding environment. At the same time, operating systems such as the *Guidance, Navigation and Control* (GNC), control the movement of a spacecraft, changing the historical role of most of these manoeuvring operations which were directed by a human (Kothari, Liberis & Lane, 2020).

4. **Collection of Data**. The use of more extensive and effective AI systems has become essential, for example, in Earth and Space Observation (EO) activities, where a huge amount of data is collected and processed. In the future, the amount of data that will be generated in an increasingly intense way by the numerous Earth Observation constellations for both civil and defense and security use will generate the operational need for suitable AI-based processing tools (ASI, 2024). Spatial big data, when combined with "Big Data Analytics," delivers "value" from big datasets, whose volume, velocity, variety, veracity, and value is beyond the ability of traditional tools to capture, store, manage and analyse the sheer volume of data (Gal, Santos, Rapp, Markovich, & van der Torre, 2020).

5. **Safeguarding and protection of Space Assets**. AI represents a key player in the development of automatic collision avoidance system, improving the process of real-time decisions in space and reducing the risk of in-space collisions.

The development of space activities and the innovation of AI systems seem to go at the same speed: with the increase in complexity and the amount of data managed in the space sector, the integration of AI systems represents an unprecedented technological and strategic breakthrough.

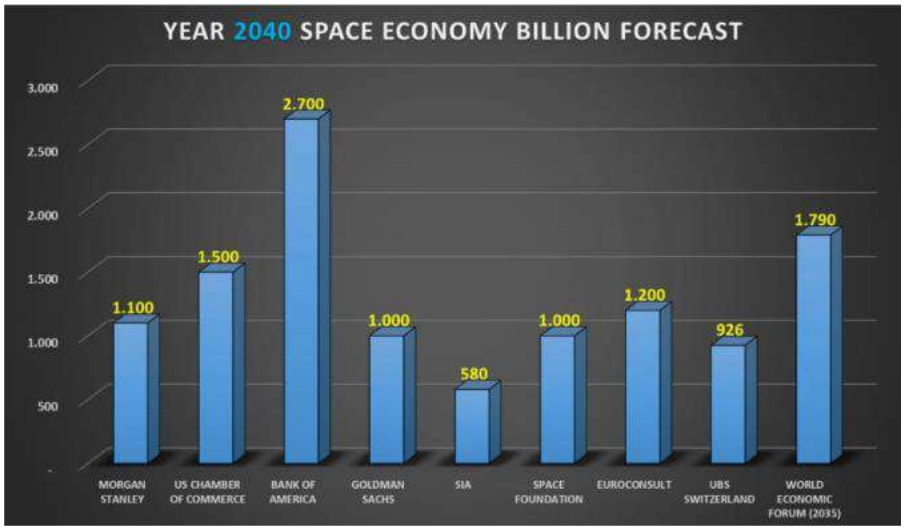

Table 1: Forecast of the value of the Space Economy by 2040. (Source: ASI, 2024)

This is even more evident if we analyze the economic impact derived from the collaboration between the two sectors: it is taking shape as one of the cornerstones of the new paradigm, which has now become famous, of the *New Space Economy*, a central lever in the conformation of the new perception of space as a strategic asset for economic growth and industrial development. The New Space Economy, in fact, attracts investment from private entities, emerging governments, local authorities and universities (Rementeria, 2022).

Table 1 (ASI, 2024) compares the forecasts on the value of the Space Economy by 2040 drawn up by various institutional and financial actors, with the exception of the World Economic Forum, whose data refer to the year 2035. Estimates vary widely, ranging from $2,700 billion indicated by Bank of America, the most optimistic forecast, to $580 billion by the Satellite Industry Association, the most cautious. In the middle are intermediate valuations such as those of the World Economic Forum, the US Chamber of Commerce, Euroconsult and Morgan Stanley, which range between 1,100 and 1,790 billion. This wide variability reflects both the complexity of the economic dynamics related to space and the different methodologies adopted, but in any case, testifies to a growing consensus on the strategic role that the Space Economy is destined to assume globally in the coming decades.

A further study by Euroconsult (2024), predicts that the Global Space Economy will be worth almost $750 billion by 2030, with a *compound annual growth rate* (CAGR) estimated at between 7.5% and 11%. Within this system, the implementation of AI systems in spatial processes represents a transversal technological amplifier, influencing both the operational efficiency and the economic profitability of the services and infrastructures involved (European Parliamentary Research Service, 2024). Other aggregated data covering the entire AI sector in the space and aerospace sector predict that the market is set to exceed the value of $1.8 trillion by 2030, with constant growth driven by the convergence of digitization, big data and sensor miniaturization (ASI, 2024). Not only that: the large-scale adoption of new AI technologies, with particular reference to ML processes, will allow an

estimated cost reduction in the aerospace sector of up to 25% of current ones by 2030, with cascading effects on the competitiveness of the entire sector.

The advantages and potential benefits associated with the integration of AI into space activities seem, as seen, to offer a future with unlimited potential in terms of operational efficiency, sustainability and innovation. These factors have made Space a place where it has become essential to affirm its autonomy and solidity, both economically and politically. Continuous updates and deployments also require a high level of security and robustness. The following table, prepared by the ASI, shows a summary of a SWOT (Strengths, Weakeness, Opportunities and Threats) analysis related to the use of AI systems in the space domain.

Opportunities	**Threats**
Support for human missions: AI can assist astronauts in real time by monitoring vital signs, environmental conditions, and potential hazards.	Cyber-threats: growing use of AI in space may increase cyberattacks on AI-controlled assets, creating dependency and risks in case of failures or lack of redundancy.
Innovation in autonomous navigation: more efficient missions, spacecraft rendezvous, and planetary exploration.	Ethical and legal challenges: AI in space raises issues of accountability and liability, especially for autonomous decisions, in a context with limited legal frameworks.
Better space debris management and RSO characterization: AI can track, predict, and manage debris, and identify unknown or unlisted objects, improving safety in orbit.	Regulatory challenges: technological development outpaces regulation, potentially causing accountability gaps and international cooperation issues.

Strengths	**Weaknesses**
Data processing: rapid analysis of Big Data (e.g., satellite images) improving decision-making and planning.	Complexity and costs: requires investment in infrastructure, data, and skilled personnel.
Advanced autonomous operations: autonomous activities in deep space where real-time communication with Earth is difficult.	Dependence on machine learning models: prone to errors and requiring continuous updates, retraining, and optimization.

Automation of repetitive tasks: many space operations involve repetitive activities, both in ground control centers and onboard processing.	Data limitations and quality: requires large amounts of high-quality data.
Predictive maintenance: anticipating failures through sensor data analysis.	Cybersecurity vulnerabilities: increased risks of hacking and manipulation.

Table 2: SWOT Analysis of Artificial Intelligence in Space (Source: ASI, 2024)

Alongside the advantages already listed above (collection of data, autonomous operations, predictive maintenance), the table shows some critical issues and structural weaknesses that emerge. The significant costs and know-how required to implement new AI technologies require significant investments in infrastructure, data processing and specialized skills. Second, ML models expose you to risks related to data quality and the continuous need for machine updating and optimization. In the threats box, the possible intensification of the risks of cyber-attacks on critical infrastructures are highlighted, with consequences, as we will see later, crucial. On the other hand, the ethical and legal issue related to the management autonomy carried out by non-human systems emerges in an international regulatory framework that is still fragmented and not homogeneous in the response necessary to the rapid evolution of technological innovations in the space sector.

A systematic analysis published in 2018 mapped in detail the evolution of AI in the first sixteen years of the twenty-first century, underlining how it has become a fundamental component of contemporary technological strategies (Liu et al., 2018). It is not part of the goal of this study to retrace in a detailed and chronological way the events that have characterized the history of the development of artificial intelligence up to the present day: the international literature abounds in exhaustive works that summarize the evolution of AI in the processes related both to space activities, and more generally as an autonomous scientific discipline and in its most common and everyday use. Nevertheless, in order to better understand the analysis that we intend to conduct in the following chapters, it is considered appropriate and necessary to offer a brief summary of the most relevant historical phases that have characterized the evolution of AI and its use in space activities.

1.1.1 AI: Origins and Early Applications in Space Sector

Artificial intelligence has its roots in the middle of the last century, more precisely in 1956, when the term “Artificial Intelligence” itself was coined at the famous workshop held at Dartmouth College under the guidance of John McCarthy, Marvin Minsky, Nathaniel Rochester and Claude Shannon. The event commonly represents the symbolic starting point of the discipline, marking the birth of the so-called “first golden age” of AI (Sharma, 2025). A year earlier, in 1955, Allen Newell, Herbert A. Simon and Cliff Shaw developed the first programming language designed for AI, the Information Processing Language (IPL-11), designed to allow computers to perform symbolic, rather than numerical, computations. This made it ideal for AI applications, as it allowed for the manipulation of data structures, such as lists and trees, in a way that was not possible with other languages at the time (Klu.ai, n.d.). These early developments were possible thanks to the application of the symbolic-deductive paradigm, also known as “GOFAI” (Good Old-Fashioned Artificial Intelligence), based on the idea that intelligence could be replicated through explicit logic and symbolic manipulation of structured data (Russell & Norvig, 2021). The initial interest and enthusiasm that had brought huge public funding and aroused the interest and curiosity of the academic field, was stopped in the 70s: the computational limits and semantic complexity in converting real problems to AI systems led to the first crisis in the sector also called “AI Winter” (Crevier, 1993). In particular, the “Lighthill Report” (1973) commissioned by the Science Research Council and elaborated by Professor James Lighthill provided a pessimistic view of the state of AI during the 70s, wide-ranging criticism of the ambitions and results of research.

A significant recovery took place starting from the following decade with the beginning of the “expert systems season”, the first real implementation of an operational process generated by AI. Expert systems have played a fundamental role in laying the foundations for what we know today as “Hybrid Artificial Intelligence”, capable of combining symbolic rules with statistical models. Relating to the space sector, expert systems represented the first real attempt to transfer human knowledge to digital systems, creating the basis for what are now the fields of “knowledge representation”, “data governance” and “explainable AI”, central elements, as we will see later, in current dual-use space applications. But what are expert systems? An expert system is defined as “a computer software system that has achieved a level of performance in a limited domain which approaches that of an acknowledged human expert in the same domain” (Kastner & Hong, 1984). In other words, the systems operated starting from a formalized knowledge base (where the facts and

rules that were the basis of the system were enclosed) and an inferential engine that, starting from the data entering the system, processed logical deductions and inferences. Characterized by the character of the “limited domain”, also called “domain of expertise”, initially several of the most famous expert systems were developed for medical applications and consultation (Kulikowski, 1982). The initial success was soon reduced by the technical limitations that emerged. Although the technology took hold and implemented its own fields of research, as systems became more complex, the difficulty in scaling the rules emerged, i.e. updating basic formalized knowledge, with an increasingly expensive cost. In addition, the systems struggled to manage the ML processes: any variation of the initial domain required the human hand, of a “knowledge engineer” who manually updated the knowledge of the machine. All this combined, gave rise in the early 90s to the so-called second AI Winter (Crevier, 1993).

A new breakthrough came with the adoption of connectionist approaches, especially with the revival of “artificial neural networks” (ANNs) at the basis of statistical machine learning. Connectionist AI models are based on the biological assumption that the human mind emerges from the distributed functioning of neural networks in the brain, artificial nodes connected to each other, capable of weighing and transmitting signals, according to feedback and adaptation mechanisms (Rumelhart, Hinton & Williams, 1986). Initially used in purely academic contexts, ANNs began to find space for application in the aerospace field, where they were applied for the processing of unstructured sensor data, analysis of risks derived from new space missions, monitoring and prevention of possible failures in orbit and, last but not least, for the on-earth modelling of unknown remote environments not yet directly observable. This new kind of application was also possible thanks to the emergence of a new paradigm of machine learning, Reinforcement Learning (RL), a branch of ML that bases its function on machine learning through its interaction with the surrounding environment. This ability to “learn by experience” allows an intelligent agent to optimize their decisions, reducing the amount of labeled data needed, as a function of a reward or penalty (Sutton & Barto, 2018). Think, for example, of space missions to Mars: the communication time between the rover and the bases for sending commands from Earth can exceed twenty minutes. It is therefore necessary to adapt robots through RL systems, thus capable of making decisions autonomously as demonstrated by the “Nasa Curiosity” and “Perseverance” projects, which already implement semi-autonomous decision-making architectures based on AI and RL modules for navigation and management of operational anomalies (Oche et al., 2024). Other examples, as we will see later, of RL application concern, among others, its fundamental use for the operation and operability of satellites

in orbit, in the thermal management of space modules and in the energy management of on-board payloads (Ibid.).

1.1.2 Fields of Application

Given the difficulty in applying a unique taxonomy to spatial processes, a good starting point for understanding and analysing the fields where AI is most applied is the use of the division adopted by the Organization for Economic Cooperation and Development (OECD), between *upstream*, *downstream* and *space-related* activities and processes (OECD, 2024). It is important to underline that this division is intended to facilitate understanding for a subdivision of practices related to the use of AI systems, without delineating rigid boundaries between the three segments. Furthermore, as already mentioned above, the interdisciplinary nature, the rapid and continuous technological evolution that characterizes space processes, makes AI virtually applicable to any operational field related to the space sector.

For this reason, the list below is not an exhaustive list of all possible fields of application between the two domains. Often the three segments – upstream, downstream and space-related – are interconnected: developed capabilities, such as the management of the autonomy of satellites for collision avoidance maneuvers, have a direct impact on downstream processes by increasing their reliability and the quality of the data provided for terrestrial applications (ESA, 2019). Similarly, data analysis is of fundamental importance in the processes, for example, of designing and optimizing resources for new space missions, thus contributing to feeding every process of the supply chain of the New Space Economy in a transversal way (Hobe, 2021).

1. The **upstream** segment includes all activities directly related to space, including the design, manufacture, assembly, launch, operation, maintenance, monitoring and repair of spacecraft, such as satellites, carrier rockets and orbital platforms, as well as associated products and services (Garzaniti et al. 2021).

    a. **Guidance, Navigation & Control (GNC)** – The Spacecraft Attitude and Orbit Control System (AOCS) main tasks concern the tout court control of the movements

of spacecraft in space, commonly known as GNC, an engineering branch that includes the set of techniques and architectures responsible for establishing and maintaining the attitude, position and trajectory of a spacecraft (Chowdhary & Johnson, 2013). In other words, the GNC control the movement of a spacecraft. By common agreement with the definition of the Defense Technical Information Center (2022) "Guidance involves the vehicle's current location and trajectory to a designated target, as well as desired changes in its velocity, rotation, and acceleration for following that path. Navigation involves the vehicle's location and velocity (its state vector) and its attitude (angular position in space). Control involves the application of steering controls needed to execute guidance commands while maintaining platform stability and smooth travel to the target." (DTIC, 2022). Historically, these actions were managed and directed through coordinated intervention by human action, for missions that were only possible near Earth. The introduction of new AI algorithms has revolutionized CNG systems through, in particular, ML and RL techniques capable of making spacecraft learn optimal strategies tested through interaction with the environment in which they operate, without the need for continuous control by the command center (Sutton & Barto, 2018). A sub-section of ML, Deep Learning (DL), allows a greater degree of autonomy and resilience to GNC systems, which is particularly important for deep space missions that suffer from lag and gaps in communication (Kothari, Liberis, & Lane, 2020). One of the most emblematic examples of the adoption of GNC systems is represented by NASA's Martian rovers operating on the surface of Mars: Curiosity, operational since 2012, was the first rover to integrate semi-autonomous navigation modules capable of autonomously processing the images collected through its cameras, managing to recompose the environment of the red planet on which it operated through three-dimensional maps. Autonomous Navigation (AutoNav) has made it possible to drastically reduce the time delay in communications (which can reach up to 20 minutes) between rovers operating on Mars and operational bases on Earth.

b. **Space Situational Awareness (SSA) and Collision Avoidance** – The exponential increase of space debris in outer space in recent years has increased the significant risk of collision for both spacecraft and satellites, with possible damage or even possible mission failure, making space debris a crucial issue for space exploration (Arshad,

Bazzocchi, & Hussain, 2025). To manage spacecraft collision challenges, space operators and researchers have developed tools for conjunction assessment and mitigation strategies (Kim, Lee, Cho, & Seong, 2018), and the new algorithms based on RL have been particularly successful, demonstrating how it is possible to reduce risks to orbital assets through autonomous decisions (Patnala & Abdin, 2024).

c. **Predictive Maintenance and On-board Resource Management** – Unlike traditional preventive maintenance, predictive maintenance offers new scenarios to anticipate and counteract possible failures, malfunctions or anomalies in space subsystems, exploiting the real-time analysis of the data collected from on-board sensors. Some examples. Using ML algorithms for continuous monitoring of power management units and thermal systems enables the detection of anomalous patterns that would not be possible to detect (Goodwill, Wilson, & MacKinnon, 2023). The "Digital Twin" approach, proposed by Grieves & Vickers (2017), allows accurate predictions to be made about the state of degradation of various components, thus allowing the lifespan of an object in space to be extended (Grieves & Vickers, 2017).

2. The downstream space segment includes the set of activities, operations and services that transform space infrastructures into applications with a direct impact on Earth. In other words, when we talk about downstream, we refer to the processing of data generated in orbit to produce added value on Earth (ESA, 2023). It does not only include space operations with utilities directly attributable to terrestrial purposes but a whole series of services dependent on the operation of satellite technologies. In its most common meaning, in fact, the downstream segment is associated with services based directly on satellites – such as TLC, GNSS services or related to Earth Observation – but its scope proves to be much broader, managing to also include all activities related to both the processing and integration or transformation of space data with other external sources. Through the integration of new emerging digital technologies, the link between space data and third-party sources has made it possible to extract new knowledge useful for economic and environmental purposes (OECD, 2024).

    a. **Precision Agricolture (PA)** – Also known as "smart farming", PA refers to the ability to collect, process, and analyze spatial and temporal data to optimize field management practices (Cisternas, Velásquez, Caro, & Rodríguez, 2020). In response

to epochal changes such as climate change and environmental sustainability, the system is based on the integration of the various Remote sensing (RS) systems applied to agriculture, with aerial or satellite data (Saki et al., 2024), in order to optimize the sector's decision-making processes. However, the acquisition and processing of images from space combined with the maintenance and operation of RS systems can be expensive and resource-intensive processes, limiting the accessibility of some agricultural operations (He, Liang, Wang, Shuai, & Yu, 2014). In this context, ML and AI have emerged as crucial tools, automating the process of identifying patterns, anomalies in agricultural monitoring, improving their accuracy for new predictions and real-time monitoring in agriculture (Saki et al., 2024).

b. **Market intelligence & Policy support** – A second area that has been rapidly evolving in recent years includes the use of AI to enhance spatial data no longer only in a technical sense (applied, i.e., to technical operational fields such as the PA), but also from an economic and political perspective. The use of new ML algorithms allows the creation of new models for a better definition of future economic scenarios, optimizing the implementation of industrial policies related to the Space Economy (OECD, 2024). The adoption of AI-based predictive methods allows players in the financial sector to assess the appropriate allocation of risk capital, improving the accuracy of both the forecast of investment risk and the potential growth of space companies (European Investment Bank, 2022).

3. The last segment is that relating to **space-related** operations, i.e. all products and services deriving from indirect applications in the space sector, usually through technological spin-off or technology transfer phenomena (OECD, 2023). While using satellite technologies, space-related operations do not depend on them to function, leveraging AI systems to integrate "space value" into economic ecosystems on Earth.

1.2 Different Satellites

The launch of two small satellites, Sputnik (83 kg) and Explorer-1 (14 kg), respectively from the former USSR and USA started the so-called “Era of Satellites”. It is their era: with the technological standards of this century, it now seems impossible to do without these objects - sometimes very large, sometimes just 10 centimeters large and weighing 300 grams - which allow us to perform functions considered basic and obvious in everyday life (Finucci, 2023). The data tell us that since the first launch in 1957, about 23,030 satellites have been launched into orbit, of which 15,280 would still be in space and, among these, 12,500 would still be functional (ESA, 2025).

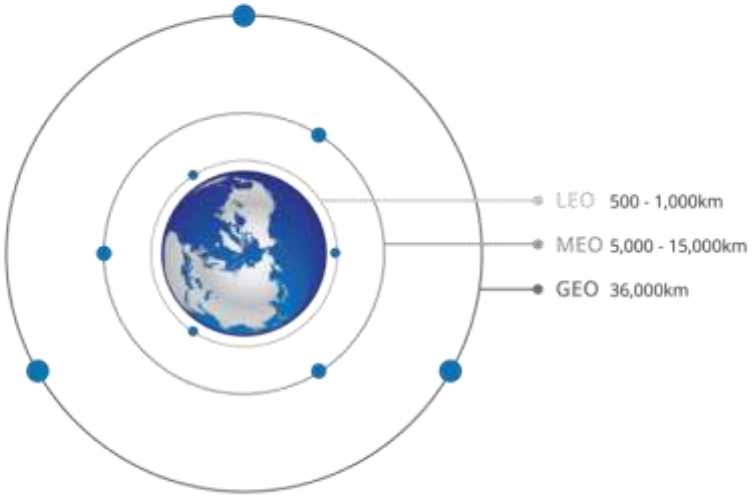

Figure 1: Satellite orbits. (Source: NanoAvionics, 2023)

Figure 1 shows the three main categories of Earth orbits – Low Earth Orbit (LEO), Medium Earth Orbit (MEO) & Geostationary Orbit (GEO) – and their different distance from Earth, in which satellites operate their functions. Each orbit has its own peculiarities that are reflected in the different use of satellites operating within it:

1. **GEO satellites** fly above the equator, traveling a path that corresponds exactly to the Earth's rotation: 23 hours 56 minutes and 4 seconds to complete one full orbit (ESA, 2020). For this reason, satellites in GEO are also called geostationary because, seen from the ground, they appear motionless in the sky (Voelsen, 2021). They are located at an altitude of about 35,000 km from the Earth's equator, a significant height for all activities that require rapid data exchange (Coughlin, 2023). They are ideal for satellites that need to remain stationary on a specific point, such as satellites operating in the telecommunications field, with the ground antennas stationary in a single position facing the reference satellite (ESA, 2020). GEO is also a widely used orbit for meteorological satellites, being able to capture continuous data over time from specific regions, useful for projecting future weather trends. Given their distance from the ground, one of the great characteristic advantages of satellites in GEO is the large coverage of the portion of the Earth that they are able to guarantee: just three evenly spaced satellites can provide near-global coverage (Ibidem).

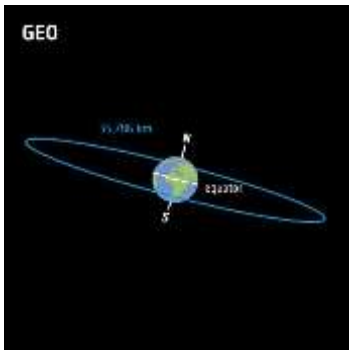

Figure 2: GEO (Source: ESA, 2020)

2. **MEO satellites** are located in the wide range between LEO and GEO operating at an orbit between 5,000 and 15,000 km (Ibid.). For this reason, the MEO orbit is particularly suitable for satellite navigation systems (GNSS) (Coughlin, 2023), including the Global Positioning System (GPS), the Russian GLONASS global navigation satellite system and the Chinese one, the BeiDou (Chinese for "Big Dipper"). Its distance from Earth allows it to achieve an optimal balance between global coverage, signal accuracy, and the number of satellites needed to achieve global coverage of the globe, providing an ideal compromise for applications that require reliability, accuracy, and fast response times. In addition, the intermediate distance with respect to satellites operating in LEO leads to a lower vulnerability of the satellites, increasing their resilience fundamental for security and defense applications.

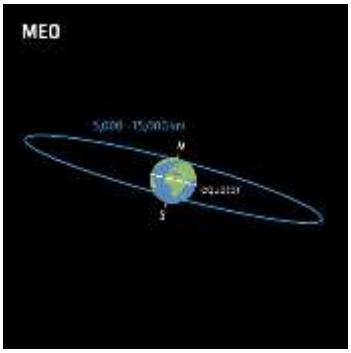

Figure 3: MEO (Source: Author's elaboration based on ESA, 2020)

3. Unlike satellites in GEO that orbit along Earth's equator, **LEO satellites** can have their orbital planes tilted at various angles (ESA, 2020). The proximity of the orbit to the Earth's surface makes it one of the most dynamic areas of the space economy. Satellites in LEO are characterized by revolution times between 40 and 100 minutes, offering very low latencies (about 0.05 seconds) (Gennaro, 2022); moreover, unlike satellites in GEO that must always orbit along Earth's equator, LEO satellites do not always have to follow a particular path around Earth in the same way (ESA, 2020). Through the now common use of constellations, satellites in LEO are essential, among others, for communication services, global Internet coverage and the ability to enable connectivity even to remote regions of the globe (Zhang et al., 2022). Finally, LEO is home to the International Space Station (ISS), the largest orbiting laboratory ever built, located at an altitude of about 400 km. ISS has been continuously inhabited for over 20 years, hosting over 260 individuals from 21 countries comprising over 60 Expeditions (NASA, 2023).

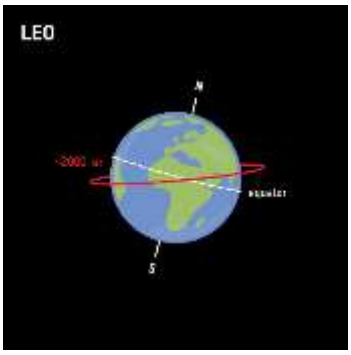

Figure 4: LEO (Source: ESA, 2020

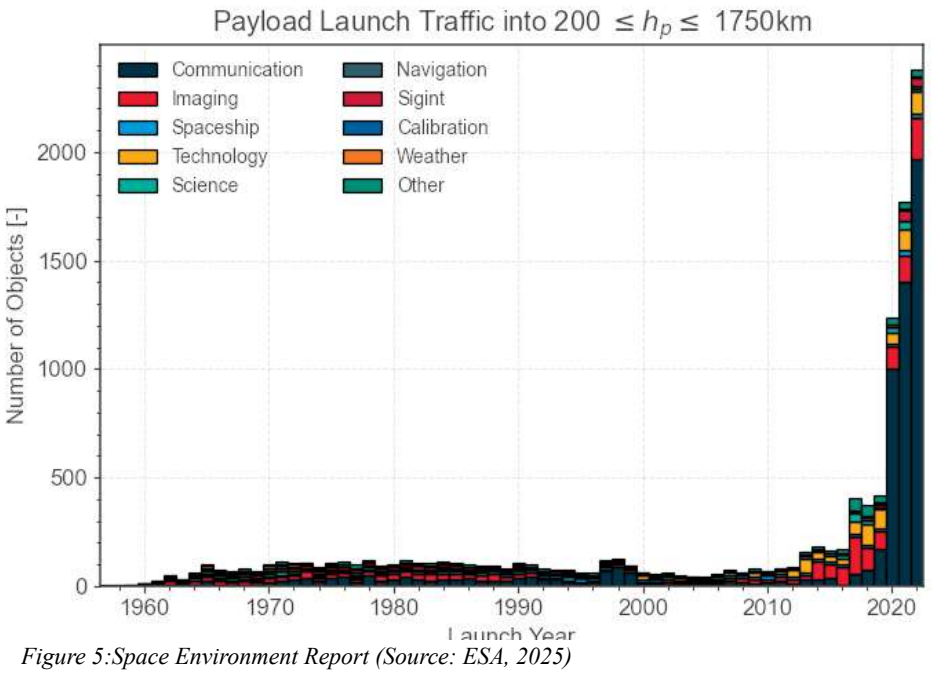

Figure 5:Space Environment Report (Source: ESA, 2025)

The different orbits offer different optimal and efficient possibilities for the use of satellites, which over the years have become one of the sources of primary interest for both sovereign states and private operators. Thanks to technological advances, an increasing number of new enterprises has entered the market (Gili & ISPI, 2024). The dawn of the 21st century has witnessed the burgeoning of space commerce, a new frontier characterized by the increasing involvement of private entities in space activities (Uwaoma, Eboigbe, Eyo-Udo, Daraojimba, & Kaggwa, 2023). Elon Musk, Peter Thievel, Jeff Bezos,

Palmer Luckey are just some of the names that with their companies have revolutionized the market of the "New Space Economy" by increasing the number of new activities and objects launched into space. According to McKinsey, the price of heavy launches to LEO has tumbled from $65,000 per kg to $1,500 per kg and the ongoing development of Spacex's Starship, could further reduce costs with a new target launch cost of $100 per kg to LEO (Gili & ISPI, 2024). Therefore, the number of overall objects launched – Payload (PL) - into outer space has raised in the last decade: most of them, equal to about 80–85%, have been placed in LEO, 5% have reached MEO, mainly for satellite navigation systems, and finally, about 10–12% have been placed in GEO, where mainly telecommunications and broadcasting satellites operate (UNOOSA, 2024).

1.2.1 Satellites Mass-based Classification

In this new scenario, satellites become not only tools for observation, communication or defense as we will see later, but take on the character of central elements of global digital infrastructures, on which the technological transformation of contemporary societies has its roots (Pelton, 2017). Not all satellites are the same, as we have seen, differing from each other based on their application, orbit but above all on their size. Since the twenty-first century, we have been able to witness a "miniaturization" of mass and size of the satellites. In the period between 1950 and 1990, the continuous increase in space launches was accompanied by an increase in the effective size in size, effective volume (mass) and cost of satellites put into orbit (Kramer & Cracknell, 2008). A reversal of course was mainly due to the progress in the field of microelectronics, starting from the 80s, which also led to a reduction in the costs of both production and launch in the space sector, followed at the same time by an increasing complexity in the setting of the new configuration of the satellites, smaller and more efficient (Botelho & Xavier, 2019). The growth of interest in "SmallSats" was also caused by the enormous interest in LEO, the orbit that best reconciles the ratio between $/kg delivered to orbit, thanks also to the Sun Synchronous orbit, the most popular orbit in the segment for small satellites, which guarantees satellites of constant sunlight (Sandau, 2020).

The mass-based classification is useful to study the advantages and the technologies used in different class of satellites. The classification ranges of mass of the small satellites vary with organisations and users (Murugan & Agrawal, 2020).

Class	*Mass (kg)*
Large Satellite	> 1000
Medium Satellite	500 - 1000
Small satellite	<500
Mini Satellite	100-500
Micro Satellite	10-100
Nano Satellite	1-10
Pico Satellite	0.1-1
Femto Satellite	<0.1

Table 3: Mass-based classification of satellites (Source: Murugan & Agrawal, 2020)

The main distinction between this classification is the sub-group of **small satellites** which are commonly known as all the satellites with less than 500 kg mass (Ibidem).

- **Large satellites**, defined as platforms with a mass of more than 1,000 kg, they represent the traditional architectures implemented since the 70s. Thanks to their size, they guarantee large payload capacities for long-duration missions (five to ten years), essential for telecommunication or meteorological satellites in GEO, and a strategic return in terms of service continuity (Pelton, 2017). They generate more power with bigger deployable solar panels to support all subsystems and bigger payloads (Murugan, 2017).

- **Micro satellites**, in the 10-100 kg range, they constitute one of the central pivots in the recent development of space activities. They are characterized by their low cost compared to large satellites and can be used in heterogeneous contexts, ranging from environmental monitoring to propulsion systems. What most identifies and characterizes them compared to its peers is their main use in constellations of satellites and formation flying (Ibid.).

- **Nano satellites**, They are typically small objects with a mass ranging between 1-10 kg that take advantage of the already mentioned advantages of the low cost of development and launch. Most nanosatellites are not brought into orbit through specific, dedicated launches, but through the use of secondary LPs in “shared rideshare” missions with a larger main PL. In fact, Nano satellites “hook a passage” to the desired orbit at significantly lower costs (Astroforge, 2025). A specific category of nanosatellites is called **CubeSats**, based on the standard of CubeSat unit – 10 x 10 x 10 cm cube that weighs between 1 and 1.33 kg (Fevgas et al., 2025).

1.3 Dual-Use Concept and Militarization of Space

Through a rapid reconstruction we tried to make a brief recap about the use and the main differences between the satellites in orbit. We have seen the various orbits in which they operate (GEO, MEO, LEO), the different sizes they can assume, ranging from real giants of space to very small cubes of a few cm. Some of the civil fields of application that satellite activities directly or indirectly feed in the upstream/downstream segments were then observed. A so-called "civil" use of satellite operations has therefore been observed, through which it is possible to accurately predict tomorrow's temperatures in Toronto, observe and predict events that could change the conformation of a lake or optimize the agricultural harvest of a given field.

The history of the development of space activities has not been characterized, however, by their use for mere civilian purposes, in order to implement international cooperation between states and the peaceful purposes derived from space exploration (United Nations Office for Outer Space Affairs, 1967). In 1991, during the Gulf War, the INMARSAT system transmitted, almost instantaneously, via portable satellite ground terminal's firsthand view of the fighting at the front to the Pentagon (Kiernan & Saunders, 1991), thus giving a vivid illustration of the new central role that military, but above all civilian, satellites would assume during an international crisis of such caliber (Morgan, 1994). In 1989 there were already fifty states that owned and used satellites mainly for telecommunications and broadcasting needs (Rees, 1989), such as France and its satellite system TELECOM, Italy (Italsat), Japan (N-Star series, Sakura series) but also countries such as Iraq (INTELSAT services). Although they were registered as communications satellites, at the time it was difficult to ascertain from the registries whether the satellites so registered are being used for military purposes (Morgan, 1994). The example of France and Russia is significant: both countries registered the following satellites as using the C-band in geosynchronous orbit (GSO) for "government" purposes: France's TELECOM series and Russia's Raguda series, Prognoz series, and Gorizont series (Ibidem). What the term "government purposes" means is still not further defined.

Since the start of the Space age in the 50', the international community and the states have tried to keep track of the new objects launched into the outer space. This process was considered as a natural process for any nation (Hertzfeld, 2021) that have tried, since the beginning of human existence, to track, monitor and analyse things visible in the sky. The draft of the first space treaty - Outer Space Treaty, 1967 – created a new international model for the registration of the orbital satellites. Article VIII of the treaty is the juridic fundamental which establishes the connection among

a State and its space object: “A State to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and over any personnel thereof, while in outer space or on a celestial body (…)” (United Nations Office for Outer Space Affairs, 1967), so three main principles to register an object launched in outer space were established.

1. The State that registers a space object retains “jurisdiction and control” over that object and all personnel on board;
2. The object remains under the jurisdiction of the registrant state even if it is in outer space or in orbit around the Earth;
3. If the item is returned from another state, it must be returned to the state that registered it;

Although the treaty still represents the first and one of the few attempts to regulate human presence and activities in space by the international community, it did not obliged states, or other organizations, to classify the functions and the scope of the objects launched in the outer space. Nor was requested the general application of these new objects. In 1976, the UN General Assembly with its “Convention on Registration of Objects Launched into Outer Space” (United Nations General Assembly, 1976) tried to overcome some of the previous issues. It instituted a new procedural for States that have to communicate to the UN more details, as Article IV states:

1. Name of launching State or States;
2. An appropriate designator of the space object or its registration number;
3. Date and territory or location launch;
4. Basical orbital parameters;
5. General function of the space object (Ibidem).

The last point, “the general function”, still represents one of the most problematic and controversial point of discussion both for academic literature and political scope of the States. This definition is not accompanied by uniform criteria or detailed obligations establishing its limits and reference boundaries, nor is there an independent verification procedure by the United Nations or third parties. As the example of France and Russia mentioned before, nations can easily overcome this “ambiguity” by using standard statement as the “government purposes”, “communications”, “remote sensing” and many others which permit to do not inform and register satellites and other objects as military one. Moreover, national security regimes and military secrecy allow states to protect information considered sensitive, helping to deliberately keep the distinction between civilian and military capabilities opaque. In the end, as Jakhu and Pelton (2017) observed, the international registration system seems to reflect a political compromise between states and organizations instead

of guarantee technical transparency: States do not want to be responsible for their actions in space and do not want to let other rivals to be informed about their spatial programs (Jakhu & Pelton, 2017).

The concept of **Dual-Use** refers precisely to the ability of a technology to be used in applications with both civil and military purposes, very often without being able to delineate a clear distinction between the two purposes. It is no longer, therefore, the initial design of a technology that demarcates its civil or military field of application but rather the purpose with which it is intended to be used. The crucial role that these technologies play in the current geopolitical scenario is implicitly deduced: a small example is the adoption, in January 2024 by the European Commission, of the "White Paper on options for enhancing support for research and development involving technologies with dual-use potential" (European Commission, 2024). Among the technologies consulted in the document we find: artificial intelligence, advanced materials, nanotechnology, cybersecurity tools, biotechnologies, quantum and more. Space is no exception: already in 2013, the conundrum of space-related dual-use technology presents itself when an estimated 95% of space technology can be considered dual-use (Pillai, 2016). Most orbital infrastructures provide services that, depending on their use, can be simultaneously useful for activities that are distant from each other such as environmental monitoring and the national security of a state. This makes even more implicit the real discrepancy between the assumptions outlined by the first treaty, already cited, of the United Nations "Outer Space Treaty" (OST) (United Nations Office for Outer Space Affairs, 1967), and the regulatory registration of new space objects as seen above. Thus, Space is no longer seen as a "sanctuary" (Dickey et Robin, 2020) where peaceful uses, the avoidance of conflict and freedom of movement were strategic objectives. Therefore, despite their initial purpose, common Earth observation satellites are instead able to track movements of troops, tanks and military equipment of certain enemy state, while space-based radars can be used to track aircraft and naval vessels and, lastly, satellites used for the study of X-ray sources and solar activities are able to intercept radio waves (Delle Fave, 2023). That said, this difficult distinction among civil and military use of technology in space – Dual Use – has created two different scenarios: on one hand, the total expenditure for space activities has raised both for public and private investors. On the other, the role of private space actors in contexts such international crisis and new terrestrial conflicts is now considerable.

This is why the concept of "**militarization of space**" involves not only States and supranational entities but also private commercial operators, making the space domain one the most contested and strategically relevant environments. As seen before, more than thirty years ago it was

already clear how space was taking on an ever-increasing strategic value, alongside the classic domains of land, sea and air. Vlasic (1991), commenting on the Gulf conflict, stated that "Outer space has achieved the dubious distinction of being the most heavily militarized environment accessible to humans" and "Without satellites, performance of many military missions would become impossible, and performance of others would require large increase in the unit strengths of various U.S. force elements" (Vlasic, 1991). Therefore, the new dependence of space in currently military operations has raised its importance for all the parties involved. The growing use of, and reliance on, space for national security has also led more countries to look at developing their counterspace capabilities (Secure World Foundation, 2025). The United States is now the main military player in space, but also for a strategic orientation that identifies the orbital environment as a fundamental operational domain for maintaining global military superiority (Ibid.). The creation of the U.S. Space Force in 2019 and the subsequent publication of the official *Spacepower doctrine* and the document *Space Warfighting – A Framework for Planners* institutionalized this role, defining space as an operating environment to be protected, controlled, and dominated (United States Space Force, 2025a; United States Space Force, 2025b). The U.S.A. space doctrine believes that the dependence of the U.S. Army from orbital infrastructures is now so deep that is considerable "essential" for any military campaigns. And this let us better understand why, besides common military capabilities for national security, States are investing and adopting new counterspace capabilities that can be used to deceive, disrupt, deny, degrade or even destroy space systems (Secure World Foundation, 2025).

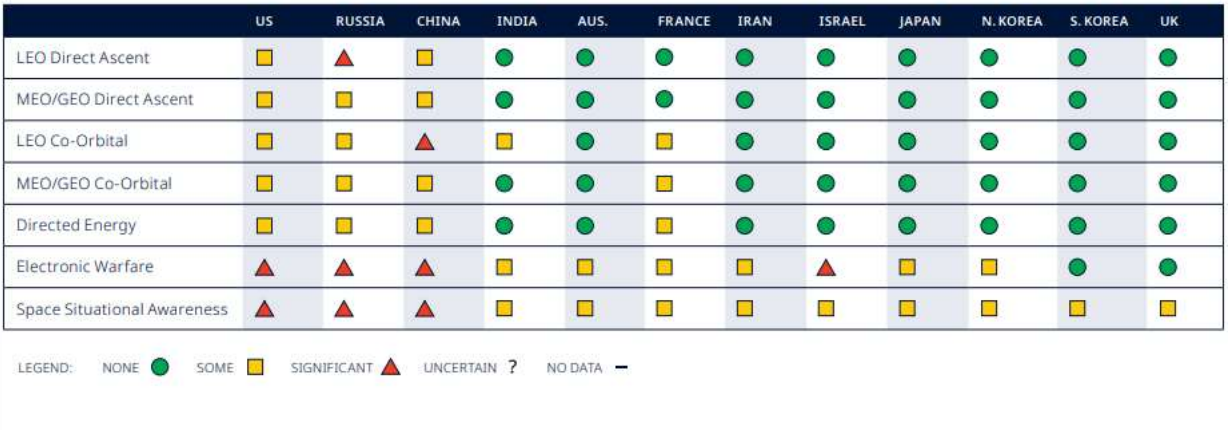

Figure 6: Counterspace Capabilities (Source: Secure World Foundation, 2025)

As the Secure World Foundation Report (2025) has shown, the existence of counterspace capabilities is not something new, but the incentives for their development and potential use are now crucial. The report describes each country's counterspace capabilities among five categories: direct-ascent, co-orbital, electronic warfare, directed energy, and cyber (Ibidem). However, only non-destructive capabilities have been used since nowadays against others space infrastructures in military operations. But States, since the Cold War epoque, are projecting counter measures to possible attack (and destroy) enemy space infrastructure. The Anti-Satellite Weapons (ASAT) constitute one of the most significant examples at regard: U.S.A., China, Russia and lastly India, which in 2019 with the test "Mission Shakti" has been able to intercept and destroy one of its own satellites in LEO (Goswami, 2019), are the four countries that have developed and positively tested ASAT systems. Among the risk generated by the possible application of such technologies, there is the crucial proliferation of new space debris in LEO. When the Chinese missile SC-19 destroyed the weather satellite Fengyun-1C in 2007, more than 3.000 fragments were generated, drawing international attention to the risks of destabilizing the orbital environment (Wright, 2007).

Lastly, besides these traditional main actors, States and supranational alliances, many private actors are now emerging in the thief balance of the Dual-Use capacity systems. New private constellations, projected and elaborated as "commercial constellations", have raised the Dual-Use nature of the orbital infrastructure. SpaceX, Maxar Technologies, Airbus Defence and Space, Blue Origin, Planet Labs, Spire Global are just few examples of the multitude of new private players, who with their assets are now playing a pivotal role inside terrestrial conflicts. This is why Schaner & Bowen (2024) have defined the new "privatization of military space power" as new structural change of paradigm inside conflicts scenarios where private companies can give crucial information to the countries involved (Schaner & Bowen, 2024).

1.4. Conclusion

The advantages and risks associated with the progressive intertwining of space assets, dual-use technologies and new AI systems have accelerated an increasingly growing phenomenon: regardless of their geopolitical weight, almost all states and, as we will see later, many international

actors are trying to equip themselves with their own satellite systems consisting of constellations, for both civil (earth observation, communication) and military (security) uses.

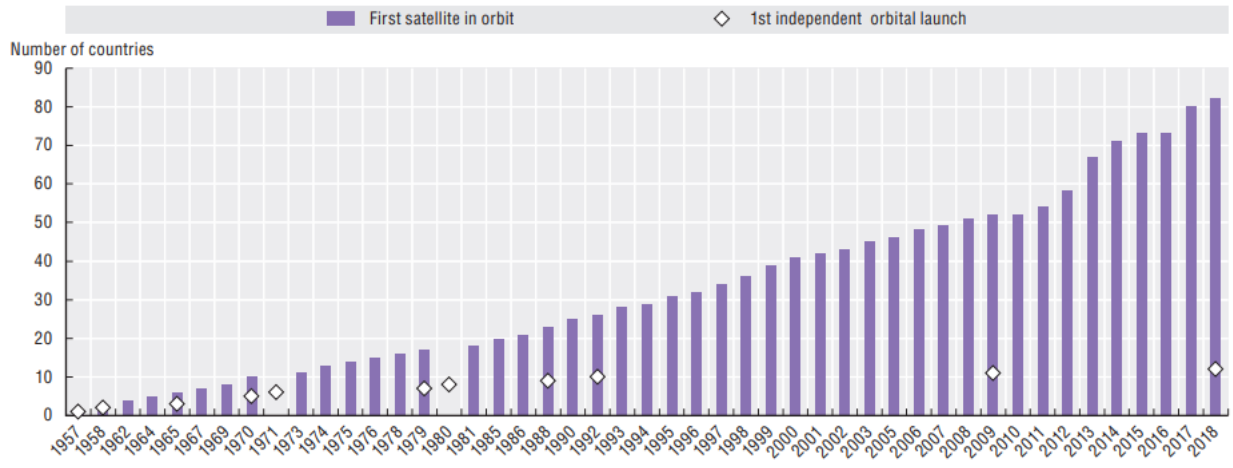

Figure 7: Number of countries with a satellite in orbit (launched via a third party or independently between 1957 and April 2018) and number of countries having launched a rocket successfully (Source: The Space Economy in Figures, OECD 2024)

In support of the new trend, the OECD report "Space Economy in Figures" (2024) analyzes how more than 80 states have, to date, an active space program. Among them, 55 are equipped with autonomous EO capabilities, a number that is up compared to the data analyzed for the previous decade (OECD, 2024). Many factors influenced these data. As already widely seen above, the greater accessibility of space made possible through new technologies and the reduction of costs for production, assembly and launch of new space objects, have been (and still are) crucial elements to ensure that new players can develop their own dual-use constellations. However, other geopolitical factors have contributed to accelerate this process.

The Russian invasion in Ukraine in February 2022 represented a real turning point. The Russian cyber-attack against Viasat's KA-SAT system, which took place in the first hours of the conflict, represents one of the most relevant episodes in recent years to understand both the vulnerability and the crucial role of space infrastructures in crisis scenarios. The attack, attributed to cyberwarfare units of the Russian GRU, compromised the network's modem management system, disabling thousands of terminals used by both Ukrainian civilian users and the armed forces and critical infrastructure (Barnes & Sanger, 2022). In the details of the attack, it is important to underline, as highlighted by ENISA (2025), that the satellite as such was not attacked but, rather, a peripheral element of its architecture, demonstrating even more how components that may be marginal at first glance actually have large-scale consequences (ENISA, 2025). The implications of the attack have had an impact not only on Ukrainian territory but have involved many other European states. In

addition to the communication blackout in several Ukrainian regions, Internet services provided via KA-SAT were also interrupted in Germany, Poland, the Czech Republic and Italy. In Germany, hundreds of German wind turbines have lost the ability to communicate with remote control systems because they are dependent on KA-SAT-based connectivity. The attack testified to how dependence on non-European private providers for essential satellite telecommunications services involves systemic risks that are difficult to manage in contexts of conflict or geopolitical instability (European Commission, 2023).

Thanks to Starlink's providential contribution, Ukraine has been able to re-establish critical connections for the government, the armed forces and essential services. The use of the Elon Musk's network was not limited to civil or institutional communications: the Starlink constellation was involved in numerous activities such as drone coordination and support for targeting operations in time (Marquardt, 2022). The combination of superior technical capability, resilience to Russian jamming and speed of deployment has made Starlink a central player in the information and operational dimension of the conflict. However, this new centrality of private actors within conflicts between states has opened up profound questions about the governance of critical infrastructures when they are not autonomously managed. Several episodes directly traceable through Elon Musk's account on his social network "X", have had a direct impact on military dynamics. These dynamics highlight a structural problem: when the operational continuity of a state's armed forces depends on commercial infrastructure, the will of the private provider can influence the conduct of the conflict, with non-negligible geopolitical implications.

It is in this context just described that the new Italian constellation "**IRIDE",** developed as part of the "National Recovery and Resilience Plan" (PNRR), finds its place. IRIDE's goal is to guarantee Italy autonomous access to high-resolution satellite data and the ability to continuously monitor the national territory, integrating multi-sensor technologies, advanced acquisition systems and AI-based analysis pipelines. Through IRIDE, Italy wants to position itself in the new space scenario, investing its own resources to guarantee essential dual-use services. The next chapter will analyse in more detail the structure, the project, the objectives and the governance of IRIDE trying to place it within the dynamics just examined in this Chapter: the ambiguity of the dual-use application, the risks of potential cyber-attacks, the centrality of data control and, finally, the role of AI within the various processes.

Chapter 2

IRIDE Constellation

The chapter will analyse the future Italian constellation IRIDE, a new all-Italian strategic infrastructure that will see its total implementation in mid-2026. It stands out for its avant-garde in the adoption of new optical sensors that will make it possible to monitor the Italian territory even in the most adverse conditions, making the project not only a major technological feat but a real turning point for the Italian industrial ecosystem in EO activities.

The history of the project is closely linked to the funds of the PNRR program that designed the methods, purposes and operational times of IRIDE. From the first presentations, until the last launch dated November 2025, IRIDE is respecting the timing of putting into orbit its six sub-constellations (upstream segments), which with their complementarity of EO activities, will allow a development of the services offered based on a constant dialogue with institutional users and the Italian Public Administration. In fact, it is the latter who will benefit first and foremost from IRIDE's new services, with the aim of a digital transformation of the Public Administration (GEOmedia, 2023) in line with the objectives of the PNRR. But they will not be the only beneficiaries of the project: SMEs, private citizens will be able to enjoy the services offered by IRIDE through a specific Marketplace where the services, in open-source mode, will be guaranteed to a wider audience.

If the timing and methods of implementation of IRIDE will be respected, new market opportunities, simplification of public administrative processes and an incremental improvement of EO systems will guarantee a structural advantage to Italy in the European and world space scene. Greater resilience through its own space systems and infrastructures guarantees greater security even in times of crisis (see the example of the attack on the Viasat system mentioned in the previous chapter). New opportunities and prospects increase in proportion to new risks and possible ambiguities. The dual-use nature of the project exposes the new Italian constellation to new threats dictated by possible cyber-attacks, possible manipulation of the data produced and its possible use during war scenarios. The theme, at the heart of the issue of this paper, will also be examined in detail in the next chapters.

2.1 The Genesis and Strategic Framing of IRIDE

The idea of a new all-Italian strategic infrastructure was born in a historical context characterized by profound social and technological transformations. On the one hand, the end of the COVID-19 pandemic has allowed states to be able to start reinvesting in the various strategic sectors. The genesis of the program, in fact, is closely linked to the policy dynamics initiated with the PNRR, which has guaranteed funds for the construction of new large strategic infrastructures, in the digital, energy but also space fields. This is why IRIDE is not conceived as an isolated mission but as a response to a twofold need of Italy. On the one hand, the intention is to strengthen Italy's position within the European space scenario, which has seen Italy as one of the main protagonists since its inception. Through IRIDE, European EO programmes will be given new complementary support to existing programmes, such as Copernicus and Galileo, capable of enhancing national industrial and scientific expertise. Secondly, IRIDE represents an investment in line with the needs dictated by the new global geopolitical scenario. This new model of public infrastructure will be of fundamental support for Italian public policies, thanks to the total end-to-end control of the entire value chain of the data collected by IRIDE's sub-constellations. It is no longer just a matter of guaranteeing access to satellite images, but of building a platform capable of transforming large volumes of data into services accessible to Italian institutions.

The timing of the construction of the new Italian constellation is also dictated by the guidelines of the PNRR. With the completion of the works scheduled for mid-2026, all six constellations in orbit managed by IRIDE will be fully functional. However, the nature of the program reflects the ambiguities and complexities inherent in contemporary space infrastructures. IRIDE incorporates technological characteristics typical of current contemporary dual-use systems, with a progressive convergence between civil, commercial and security areas of the space sector. Within a public and institutional governance, IRIDE responds to the need for ordinary and extraordinary Italian activities.

2.1.1 Story of the Project

Since the IRIDE mission will not be concluded until 2026, with this work, careful research was conducted on the official sites of the space agencies and entrepreneurial partners involved in

order to collect all the useful information to collect and order the main events that have brought to the actual configuration of IRIDE.

The idea of developing "one of the most ambitious and strategically significant projects at both the national and European levels" (Institute for International Political Studies, 2025) was born in 2021 during the post-Covid-19 pandemic period. It was during the drafting of the PNRR that the Italian government decided to propose to the European Commission the creation of a new large public space infrastructure, capable of providing the country with its own autonomous and continuous capacity for EO activities. For the first time, in fact, within the Italian Recovery Plan, an entire chapter of investments is dedicated to the development of satellite connections in view of the digital and green transition, capable of contributing to the development of the space sector (Ministry of Enterprise and Made in Italy, n.d.). The chapter is divided into 4 sub-investments:

- **4.1.1 Satcom**: provide the creation and development of technology and dual-use systems for the furniture of new satellite communications services for government purposes.
- **4.1.2 Earth Observation**: provides the creation of new satellite constellations, equipped with synthetic aperture radar (SAR) sensors and hyperspectral instruments, for continuous monitoring of the national land soil, sea and atmosphere.
- **4.1.3 Space Factory**: The area is divided into two lines of intervention. *Space Factory 4.0* intends to promote the creation of advanced infrastructures for the digital production, assembly and testing of small satellites, together with the creation of cyber-physical systems that allow digital twinning between the virtual and real models of spacecraft. The second, Access to Space, promotes the R&D of new innovative technologies for "green" solutions for future launchers.
- **4.1.4 In-Orbit Economy**: aims to strengthen national capabilities in emerging areas such as orbital servicing, interoperability between space platforms and global traffic management (STM) operations.

These activities are developed through the synergistic action of two main actors: on one hand, ASI is responsible for satellite telecommunications, EO, Space Factory and In-Orbit Economy. On the other, ESA is involved in selected EO activities (IRIDE program) and in the space transportation sector (Istituto per gli Studi di Politica Internazionale, 2025).

Following the official documentation released by the European Space Agency (ESA), IRIDE has been conceived since the dawn of the project as a "hybrid and modular" system composed in turn of 6 independent but interconnected sub-constellations (ESA, 2025). At the 303rd ESA Council meeting helded in Paris on 15 December 2021, ESA Member States took the fundamental decision to enlarge the role of ESA as a new provider of expertise in support of national space plans (European Space Agency, 2021). Specifically, ESA's new role provides for "accompanying" the Italian path of investments derived from the PNRR, with reference to point MC4.1.2 mentioned above. The following day, 16th December 2021, on the sidelines of the first "Italian National Space Day", held at the Italian Space Agency (ASI) headquarters in Rome, the ESA Director General, Josef Aschbacher and the Italian Minister for Digital Transition and Technological Innovation and delegated authority for space, Vittorio Colao, signed the "Assistance Agreement" concerning the activities of EO and Space transportation (Ibid.). The closer cooperation between ESA and the Italian Government had the goal to establish new teams uncharged to collect the best available competencies on the field for the IRIDE's project.

Starting from 2022, ESA started to manage both program's technical and contractual aspects, with the support of technical experts from ASI and other Italian public bodies (such as ISPRA and the Civil Protection Department-DPC). Upon completion of the development phase, the project was transferred to ASI which has been designated by Italian Government as the owner and operational manager of the system (Istituto per gli Studi di Politica Internazionale, 2025). The official denomination of the constellation, IRIDE, was announced the 18th of May 2022 by Italian astronaut Samantha Cristoforetti from the ISS, in occasion of the first mediatic inflight call. Samantha Cristoforetti, Luca Parmitano and Roberto Vittori – two Italian famous astronauts - selected IRIDE among 1.061 proposals received from 638 schools which have participated at the special competition "Spazio alle Idee" (Ministero dell'Istruzione e del Merito, 2022). The name took the inspiration from the mythology figure of Iris, the Greek god's messenger, in charge of transmitting messages directly from the Gods to humans or between the deities themselves. A communicative role similar to the one of the future constellations of IRIDE. Almost one year later, the result of the contest launched by Luca Parmitano, gave the official mission patch of the project. ESA was able to sign all the contracts with the major Italian industries before the 31st of March 2023, a crucial date for the PNRR.

On 3rd December 2022 during the event "New Space Economy European Expoforum" in Rome, ESA signed the first contracts with Argotec and OHB Italia (Agenzia Spaziale Italiana, 2022) for two main IRIDE's activities:

1. High Resolution Multispectral Mission, by Argotec (Turin). The contract provides for the development and delivery of a first batch of 10 satellites (and the development of the related Flight Operation Segment, FOS) by November 2024 with the option negotiated for a second batch of 15 satellites, to be delivered by November 2025. The industrial team, led by Argotec, includes partners Officina Stellare and Rhea System.

2. High Resolution Multispectral Mission, by OHB Italia (Milan). The contract provides for the development and delivery of a first batch of 12 satellites (and the development of the related Flight Operation Segment, FOS) by November 2024 with the option negotiated for a second batch of 12 satellites, to be delivered by November 2025. The industrial team led by OHB Italia includes partners OPTEC, Telespazio and Aresys.

A further step in the construction of the IRIDE constellations is represented by the contract signed on 27 March 2023 between ESA and Thales Alenia Space Italy (TASI), a joint venture between the Thales 67% group and Leonardo 33%. The contract is divided into two different supplies: the first is a constellation of 6 small satellites based on SAR technology, innovative satellites with sophisticated operating modes that aim to guarantee a high revisit time by providing data that can be integrated with some infrastructures already active in the space field, COSMO-Skymed second generation and Prisma, as well as Copernicus, a European programme for Earth observation and protection (Thales Alenia Space, 2023). The order of these 6 satellites has been implemented on October 16th, 2024, by a new order made by ESA for 6 additional radar-based satellites. The other initial furniture consists for an optical satellite and an option for a possible additional one. Media Lario and TSD-space, two important Italian companies in the sector, have been commissioned by TASI for the supply of the Very High Resolution (VHR) Optical Payload (Media Lario, 2024). Unlike classic satellites for EO, the optical satellite allows VHR images to be processed to produce, among others, thematic maps, quantitative surveys of environmental parameters and possible datasets integrated with SAR ones, thus representing the high-definition visual component of IRIDE. All 13 satellites commissioned by ESA, plus the optional one, will adopt the innovative and scalable NIMBUS platform. New Italian Micro Bus (NIMBUS) is the platform, the non-payload part of the satellite, developed by TASI to build microsatellites in LEO more quickly than traditional platforms, managing to adopt a modular, scalable and mass-producible system. According to data provided by

TASI, NIMBUS is designed as a “high performance” platform specific for constellations with high revisit and high production capacity, with very high data transmission capacity (Thales Alenia Space, 2024).

Satellite type	Sensing technology	Planned units	Satellite platform
Synthetic Aperture Radar (SAR) satellites	Radar imaging (X-band SAR)	12	NIMBUS
Optical Earth Observation satellite	Very High Resolution optical imaging	1	NIMBUS
Optional optical satellite	Very High Resolution optical imaging	Optional	NIMBUS

Table 4: Thales Alenia Space Satellites within the IRIDE programme. (Source: Thale Alenia Space, 2024).

In the ESA press release “*Moving ahead with Italy’s constellation of Earth observation satellites”*, the full operation of the entire IRIDE system is confirmed for June 2026, in line with the deadlines set by the PNRR. The orbital deployment phase officially opens on January 14, 2025, when the first satellite of the IRIDE constellation, the Pathfinder Hawk, was launched from Vandenberg Space Force Base in California aboard a Falcon 9 (Space X). As the name Pathfinder suggests, the new microsatellite is a prototype for one of the six IRIDE constellations. With the help of its camera-like instrument, the Pathfinder for the Hawk for Earth Observation (HEO) will show how this constellation can image with a ground resolution of just three metres.

Figure 8: IRIDE Pathfinder Hawk Satellite. (Source:ESA, 2025)

On 5th March 2025, the Pathfinder captured the first image published by ESA from the ESRIN of Frascati and the official IRIDE's channel (composed by the main social network) on March 28th. The high-resolution imagine shows the city of Rome at a resolution of 2.66 metres, which represents a quality image three times higher than the resolution available for systematic acquisition over Italy (ESA, 2025). This first image from IRIDE mark the start of a new generation of optical multispectral images from satellites both designed, processed and integrated fully in Italy. As the image beside betters shows, the new quality of EO activities will help directly both local and regional public authorities in Italy for daily routine activities, signalling an increase of satellite technology inside the routine activities. As an example, IRIDE will help public authorities in the management of town and city planning, monitoring possible changes in land coverage and for the effects of urban heat islands (Ibidem). HEO constellation has been implemented with 7 more satellites, developed by Argotec, on 23rd June 2025, when Falcon 9 have launched these new satellites in LEO that joined the Pathfinder. The simultaneous launch of seven satellites belonging to the same institutional constellation constitutes an "absolute record for Italy and Europe (ASI, 2025).

Figure 9: IRIDE first image over Rome. (Source: ESA, 2025).

A further major development – the last launch made to the date of this paper – was achieved in November 2025, with the successful launch of the Eaglet II constellation, the second operational sub-constellation of IRIDE. 8 Eaglet II satellites, on 28 November 2025, were launched into LEO from, again, Vanderberg Space Force Base (California) aboard a SpaceX Falcon 9, as part of a rideshare mission that also included other European payloads (European Space Agency, 2025). The signal acquisition from all satellites was successfully completed by OHB Italia, confirming the correct deployment and the operation status of the Eaglet II (Ibidem). The launch of these new satellites represents a decisive step in the transition from initial deployment to large-scale operational growth. The 2025 have seen IRIDE evolved from a single-satellite (Pathfinder) to a multi-constellation system with assets distributed across different sensing modalities. In the official statement for the last launch, ESA indicates that IRIDE will continue to expand its sub-constellations through 2026. The full operational capability is expected to be reached by mid-2026 but the complete deployment of all planned satellites will extend into 2027 (Ibidem).

2.1.2 Scope, Vision and Main Activities

The "constellation of constellations" IRIDE represents an end-to-end system which is composed of six sub-constellations of LEO satellites. This articulated process will seek to provide a national strategic infrastructure intended to guarantee Italy autonomous, continuous and high-resolution EO capabilities. The strategic importance of space extends beyond scientific and research objectives, with many countries and companies recognizing its significance and economic implications through technological transfers across various sectors, including defense, climate, agriculture, forestry, land, marine, and health within a One Health perspective (Orusa, Viani & Borgogno-Mondino, 2024). Despite the dizzying increase in new missions and services that directly use EO data, the geomorphology of some observation areas makes the process difficult to apply. Thanks to the application of new tools and technologies, such as the mentioned SAR, IRIDE will provide daily monitoring of each location in Italy with a ground sampling distance (GSD) of approximately 2 m (Ibidem). Being an end-to-end system, its area of expertise does not end with the simple launch and positioning of satellites in LEO but configures IRIDE as an integrated socio-technical system, in which space assets, pipelines based on AI systems, ground segments and data processing architectures contribute to forming a unified knowledge production platform. For this reason, IRIDE cannot be defined as merely a space program. Thanks to the substantial funding through the PNRR and the Complementary Fund of the Presidency of the Council of Ministers (about 1.1 billion euros in total), IRIDE will constitute a real public infrastructure for the strategic management of data.

IRIDE's vision is, therefore, consistent with the concept of public digital infrastructure, where space systems take on a central role within national information ecosystems. Its use will be essential for many types of suppliers: through collaboration with other national and European space programs (Copernicus, Galileo), IRIDE will support the main Italian public administrations in addressing hydreogeological instability, fires, coastal protection, air quality and many other fields (Ibidem). But the data that will be provided by IRIDE will not be for the exclusive use of Italian institutions. Although almost all European citizens are not aware of it, the data provided by the European *Sentinel* satellites of the Copernicus constellation are published in open source mode by the European Union on special platforms on the web, thus making them available and free to use to anyone who is able to manage the download of the images collected in the catalogue and, subsequently, to proceed with the processing of the same. Thanks to this experience, ESA has decided to operate in the common sense also for IRIDE, which bases the analysis of benefits on the study of the "Sentinel Benefit Study"

(SeBS). In practice, the methodology applied in SeBS, developed and articulated by EARSC (European Association of Remote Sensing Companies), completely differs from the classic top-down approach, as it aims to show the value arising from the application of Sentinel satellite data through an inverse, "bottom-up" approach (GEOmedia, 2023). Although this new advent of free open-source imagery is increasing the number of actors involved in space activities on the one hand, and on the other hand, a new culture of sharing key information for both sectors of public and private industry, the so-called "democratization of satellite imagery" (Abashidze, A. K., Ilyashevich, M., & Latypova, A., 2022), is at the same time generating new risks related to people's privacy, as we will see later.

The most relevant data in IRIDE's new vision mainly concerns its active role in the formulation of new Italian public policies. Through the native integration of AI tools along the entire IRIDE value chain, from the classification and cataloguing of the images obtained from the six sub-constellations to the detection and live control of possible satellite anomalies, IRIDE allows us to move from the simple description of the typical phenomena of EO activities to the elaboration of scenarios and operational recommendations (Oche et al., 2024). New "data-driven governance" tools are transforming the classic role of space infrastructures: IRIDE's new constellations are no longer thought of as mere providers of satellite images but as end-to-end systems capable of autonomously producing knowledge that can be directly used and applicable in public decision-making processes.

1. **Data acquisition**: the first important area of activity of the IRIDE constellation concerns the large collection of data through the work of the various heterogeneous and complementary sub-constellations. In the next paragraph and in Appendix A, further details of the different technologies and architectures of its sub-constellations are explained, which allow IRIDE to guarantee continuous monitoring of the Italian territory in any weather condition and with any degree of lighting. Figure 11 schematically depicts IRIDE's value chain, starting from data acquisition to the creation of

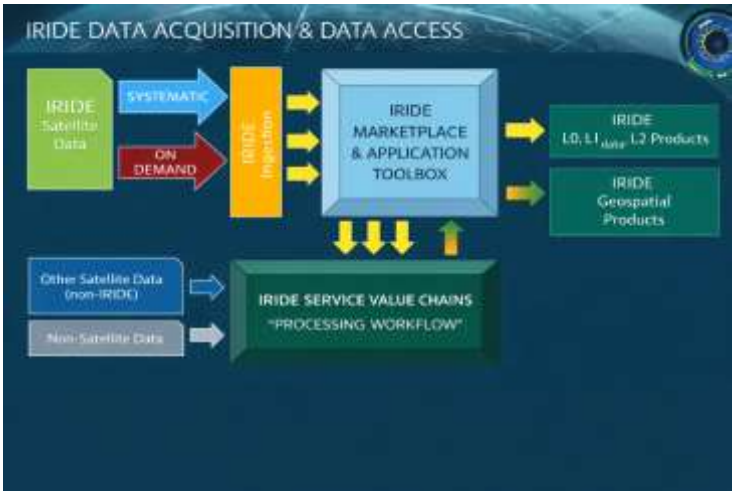

Figure 10: Acquisition and access to data of IRIDE. (Source: GEOmedia, 2023)

products available to the various stakeholders. The reliability of the data, therefore, and its temporal continuity of EO make IRIDE one of the most innovative projects within the European stage. The data acquired and collected by the IRIDE satellites are transmitted to space antennas and subsequently downloaded to a network of ground stations all over the world. The baseline configuration of the stations used for commanding the satellites and acquiring data is shown in figure 12 (European Space Agency, 2025). Once the data from the various antennas of the Ground Station Networks have been acquired, they are transmitted to the operational centers in Italy where they are subsequently processed, analysed, archived, distributed and made available for different types of use (Ibid.). In this operational phase, IRIDE's downstream, the main activities include:

Figure 11: Ground Station Network. (Source: European Space Agency, 2025)

a. **Central Mission Planning and Monitoring**, plays a pivotal role in the planning of the various activities of the entire system, ensuring a consistent and interconnected use of the data of the different constellations. In addition, the monitoring and reporting functions of IRIDE are ensured (Ibid.).
b. **Flight Operations**, responsible for sending commands to satellites, managing and planning their in-orbit operations and monitoring their functional status. Quattro Flight Operations Systems are available for IRIDE serving different constellations (Ibidem).
c. **Payload Data Ground Segment**, where data is acquired by satellites and processed to obtain EO products.
d. **Marketplace**, the platform that guarantees direct access to both IRIDE and external sources data. The Marketplace not only guarantees access to the various services but facilitates the visualization, analysis and manipulation of data (Ibidem).
e. **Cyber-Italy**, provides a digital representation of Italy (a 'digital twin'), which enables the country's current state and resource use to be analysed. It also supports virtual simulations (Ibidem).

2. **AI Integration and Data Processing**: the transformation of "raw" data acquired by satellites into information that can be used through advanced computational pipelines is facilitated through the use of AI algorithms present in all phases of the data life cycle. Although there is no information on the direct use of AI systems implemented specifically under the IRIDE program, the technologies currently used and developed for EO projects (see ESA projects Phi-Sat-1 and Phi-Sat-2) serve as essential tools for intelligent data filtration and downlink latencies. Thanks to AI systems, IRIDE will be able to move from a descriptive function to a prescriptive and predictive function. The end-to-end system, in fact, is not limited to the acquisition of data but to its processing and possible use. Change-detection algorithms can identify anomalies in land use patterns, in environmental degradation, and can support warning systems for possible hydrogeological phenomena or coastal erosion (He et al., 2014). The automation of these analysis processes will therefore also be decisive in terms of governance, transforming EO activities into a real infrastructure to support public decisions (OECD, 2024).

3. **Downstream Products and Services**: the translation of processed data produces concrete services for public administrations, research institutions (foundations, universities). Although IRIDE is oriented towards supporting functions of public interest with specific services for the Italian Public Administration (Service Segment), it has been seen that stakeholders from the private sector will also be able to use the services of the constellation through the use of the Marketplace. IRIDE will offer a wide range of geospatial services gathered in eight different domains:

    a. **S1 "Coastal Marine Monitoring"** – IRIDE's products will provide, thanks to the contribution of space technologies, environmental monitoring and mapping of the marine-coastal strip and the forecasting modelling of marine-coastal environmental parameters (GEOmedia, 2023), effectively contributing to the development of the "blue economy" and the protection of the environmental and cultural heritage of the Italian coasts. Specifically, IRIDE will support for: forecasts of the marine-coastal strip on a national scale, specific areas (ports, aquacultures, offshore platforms), mapping and monitoring of environmental parameters of coastal areas (Ibidem).

b. **S2 "Air Quality"** – The main contribution of IRIDE will concern the creation of a web service that will be complete with 3D maps from forecasting models, generated by institutional bodies (IRIDE space, 2025). Thanks to this new platform, it will be possible to make a further contribution to both the monitoring and modelling of air quality throughout the Italian territory, also creating a more accurate assessment of the sources of pollutant emissions.
c. **S3 "Ground Movements"** – IRIDE will also focus on mapping and monitoring land and infrastructure movements which can result from natural occurrences like earthquakes, landslides, subsidence phenomena (Ibidem). The IRIDE Service Segment will be able to offer this information thanks to interferometric analysis of multi-annual series of satellite data. Specifically, IRIDE will support the monitoring of landslides, cultural heritage, critical infrastructures, seismic monitoring and volcanic areas. Finally, IRIDE will produce both a digital surface model (DSM) and a digital terrain model (DTM) at a national scale at high altitude (GEOmedia, 2023).
d. **S4 "Land Cover"** – IRIDE products will support in providing processing chains and products for the definition of the state and changes of land cover, land use and consumption including the characterization of green urban areas, in accordance with the EAGLE classification system (EIONET Action Group on Land monitoring in Europe). Specific natural habitats, urban heat islands and urban green areas will be mapped (Ibidem). Land cover does not simply refer to products intended for the environmental domain in the most general sense. Other activities such as Forest Management and Agriculture will be at the heart of IRIDE's products both in qualitative and quantitative terms. In the agricultural segment, IRIDE will provide support both to processing chains and information for monitoring the effects of agricultural activities on the environment and natural resources (erosion risk, water needs), and to the CAP (Common Agricultural Policy) management system.
e. **S5 "Hydro-Meteo-Climate"** – IRIDE will provide support to national and regional efforts in weather forecasting, as well as the monitoring of hydrometeorological events, greenhouse gases and lighting (IRIDE spazio, 2025).
f. **S6 "Water Resources Management"** – Given the continuous water crises that are particularly affecting the regions of southern Italy, IRIDE will contribute to the mapping of the distribution and frequency of macro-geomorphological units, the grain

size of river sediments, post-event flooded areas, snow cover, drought indicators and possible sources of pollution in river areas (GEOmedia, 2023).

g. **S7 "Emergency"** – IRIDE's geospatial products dedicated to this domain refer to expeditious mapping to support the identification and an initial estimate of damage in extraordinary situations such as earthquakes, floods, landslides, fires, anthropogenic environmental disasters, extreme weather events.
h. **S8 "Security"** – Of particular interest for this paper, IRIDE is configured as a support element for the "surveillance of the national territory and the land and sea borders of the European Union, as well as for the monitoring of critical structures and infrastructures" (IRIDE space, 2025). Information is also provided to support the fight against illegal activities on land (illegal landfills) and at sea (oil spills) (GEOmedia, 2023)

Taken together, the activities just listed by IRIDE, the scope and integrated vision of the new Italian constellation, outline an Italian transition from traditional satellite missions to a real national space data infrastructure. The ambition of the project lies precisely in the various possible activities derived from Earth observation in support of the State, both in the form of daily public policies and related to strategic decisions in times of crisis. Italy has chosen a new resilience from external suppliers for space activities, through a new infrastructure aimed at supporting both civil innovation and national security needs in an increasingly complex and contested current geopolitical scenario.

2.2 Technology and Architecture: Constellation Design, Payloads, Segmentation

This paper does not pretend to examine in depth the technical specifications of the upstream, downstream and service segment components of IRIDE. This information is believed to be of scientific/engineering expertise. Nevertheless, a short section on the subject is necessary for a better understanding of the new Italian space infrastructure. Further technical information regarding the architecture and the PL of the six sub-constellations of IRIDE can be found in the Appendix A "Technical Specifications of IRIDE Sub-Constellations".

The IRIDE program has been conceived since the beginning as an end-to-end EO infrastructure of planet Earth based on a modular, distributed and data-centric architecture, in which the overall functionality of the system emerges from the integration between the space segment, the ground segment and the data acquisition processing platforms. From these characteristics, it is therefore possible to define the IRIDE constellation as a "system-of-systems" architecture, in more common terms a "constellation of constellations" (Telespazio, 2023), in which a common central infrastructure coordinates autonomous subsystems (constellations). From an engineering point of view, IRIDE is structured through a clear separation between the domains of planning, flight control, payload processing and data exploitation. The technical documentation of ESA, ASI and the main IRIDE suppliers describe it as an architecture in which central planning coordinates the use of the resources of the entire constellation, while flight operations are managed by dedicated systems responsible for orbital control, command & control and monitoring of the status of the satellites (European Space Agency, 2025). This separation of coordination, control and processing functions reflects a well-established architectural principle in complex spatial systems: isolation of subsystems reduces fault propagation and allows changes or extensions to be introduced in a modular way, without reconfiguring the entire system (Sandau, 2020). The adoption of multiple Flight Operations Systems, each associated with the specific six sub-constellations, also introduces a level of operational parallelism that allows high mission loads and heterogeneous assets to be managed independently, increasing the overall robustness of the architecture. Finally, as previously mentioned, the data processing domain is concentrated in the payload data ground segment, the IRIDE service segment, where the images acquired by the six IRIDE constellations are transformed into EO products through calibration, geometric correction, quality control and archiving procedures. In addition, the IRIDE satellite data will be complementary to the Copernicus and national data in the first instance and to all other auxiliary data necessary to meet the user's geospatial information need (GEOmedia, 2023). This processing chain is structurally consistent with the multi-level architectures adopted in EO missions, where the distinction between raw data, radiometrically correct products and thematic products allows metrological traceability and interoperability between different sensors and missions (Kramer & Cracknell, 2008).

2.3 Dual-Use Potential and Strategic Ambiguities in IRIDE

The technological architecture described in the previous section allows a better understanding of IRIDE's potential technical and strategic capabilities. The service segment of the constellation aims to increase the Italian industrial role in various respects, ranging from the blue economy to the substantial contribution for the main Italian Public Administrations. Nevertheless, its EO activity and the S8 segment analysed, make it a system whose capabilities intrinsically cross the boundary between civil applications and security-related uses. It is therefore correct to place the new Italian infrastructure in the broader category of dual-use technologies, which requires a broader integrated perspective of study. Of primary importance for a tout-court understanding is that IRIDE should not be interpreted only as a new Italian space project or a new strategic infrastructure but, rather, as a **critical data infrastructure**, whose technological potential, its architecture and derivative products also take on a political and strategic significance. The distance between the *de jure* foundation of the constellation, based on compliance with the legislative procedures necessary for the procurement of funds and for its operation in orbit, and its *de facto* configuration on an operational and strategic level, place IRIDE in the ambiguous ethical/legislative limbo typical of dual-use technologies. As Scheffran (2006) pointed out already twenty years ago "There is a close affinity between civil and military space technologies, both of which are facing extreme technical requirements (e.g. high speed, extreme ranges of pressure and temperature, weightlessness, radiation)" (Scheffran, 2006), the new applied technologies and its continuous monitoring of the Italian and European territory, can allow IRIDE not only to produce geospatial information but also to produce geospatial information that can contribute directly to the reorganization of the power relations linked to the control of information, surveillance and strategic autonomy.

The integration of SAR constellations in X-band (NIMBUS-SAR and NOX) allows, as seen, continuous observations independent of different degrees of illumination and adverse weather conditions, with the ability to detect surface variations and possible ground movements. However, they also coincide with the typical requirements of Intelligence, Surveillance and Reconnaissance (ISR) systems (Bowen, 2020). This overlap is not accidental: SAR technologies, capable of penetrating clouds and darkness, are ideal for monitoring environmental phenomena such as coastal erosion or fires (S4 "Land Cover" and S7 "Emergency"), but can simultaneously track the movement of vehicles, critical infrastructures or illegal activities (GEOmedia, 2023). Similarly, NIMBUS-VHR sensors and PLATINO-HYP hyperspectral systems offer detailed images for civilian applications as highlighted in S4 and S6, but their sub-metric resolution detail can allow, if intended to be used for

such purpose, the identification of military targets, such as troops or military installations, making IRIDE an asset potentially usable in defense contexts (Lewis, 2023). In addition, its full integration with European programmes such as Copernicus and Galileo, combined with the collaborative support and governance of the project by ESA and ASI, also introduce possible ambiguities in the area of project governance. On the one hand, IRIDE's contribution to the programmes and, more generally, to an institutional ecosystem based on multiple levels of operation, strengthens the resilience and interoperability of data in line with European space policies. On the other hand, although the open-source data derived from IRIDE will be inspired by the SeBS model (as seen in the previous paragraph) which attempts to democratize access to geospatial information (Abashidze et al., 2022) and aims to maximize the socio-economic impact of the data themselves, through greater transparency and ease of dissemination, such an approach may introduce new tensions for the strategic control of information. Lower barriers to access for the availability of high-resolution images and their use for advanced analytical and predictive products can increase the risks of unauthorized use by other state and non-state actors. Their possible use for military, paramilitary or intelligence operations is not excluded (Lewis, 2023).

Another field of possible ambiguity about the dual-use character of IRIDE concerns its strategic exposure to new possible cyber-attacks. These threats can encompass the entire chain of operations of the new constellation. Attacks on satellites via other satellites, once considered almost science fiction scenarios, now represent a real frontier in cyber threats, ranging from direct interference in the operations of a target satellite, the alteration or spoofing of transmitted and received data, and even the use of electronic warfare techniques to degrade communication and navigation capabilities (ICT Security Magazine, n.d.). The technical feasibility of such attacks has increased in proportion to the growing number of satellites orbiting LEO today. As pointed out by Kallberg & Thuraisingham (2020), such "satellite-to-satellite" attacks, in which one orbital vehicle can interact directly with another not only on the physical level but above all on the IT and communication level, can manifest themselves through different operating modes. Historically, satellites have benefited from a kind of "security through obscurity", according to which the skills required by the complexity of satellite constellation architectures deter all but the most sophisticated adversaries. As seen in the first chapter, the dependence on satellite services in new terrestrial conflicts make satellites primary targets within the conflict itself. An example of a possible attack is how an attacking satellite can exploit inter-satellite links to intercept and manipulate the data collected by the target. Through signal *spoofing* techniques, injecting false data, and altering communication packets, it is possible to compromise the integrity of the data exchanged between the nodes of the constellation, inducing

errors in the processing processes and in the generation of information products. If applied to the IRIDE constellation, such manipulation could have critical systemic effects, amplified in possible crisis scenarios. A further threat vector concerns the combined use of cyber warfare and electronic warfare techniques in space. Through targeted jamming, electromagnetic interference, or attacks on synchronization and timing functions, an attacking satellite could degrade the communication and navigation capabilities of another orbital asset, reduce its operational reliability or temporarily disrupt its services. Such actions, while not producing kinetic effects, can have significant strategic consequences, as they directly affect information continuity and trust in the data produced by the infrastructure (Kallberg & Thuraisingham, 2020).

An infrastructure designed for civil applications, such as soil monitoring or predictive analysis of a water emergency, can, in a context of strategic competition, become a privileged target of disturbance, sabotage and information manipulation operations. This vulnerability not only amplifies operational risks but also contributes to redefining the geopolitical significance of the program: thanks to its possible multiple uses, IRIDE is no longer just an observation platform, but a critical component of the national information ecosystem, whose protection and resilience become an integral part of Italian security policies. In this context, Italy's ability to adopt the right forms of defence for its space programmes (specifically for IRIDE) will play a fundamental role in guaranteeing the country a prominent position in the global "New Space Order". Italy's choice, as we will see in the next chapter, to equip itself with its own strategic space infrastructure for EO activities, reflects its leading role in the space sector.

Chapter 3

The New Space Order: IRIDE in the Contemporary Geopolitical Space Scenario

In the context of the so-called New Space Order, space plays a central role in the affirmation of the various states in the geopolitical sphere. Through increasing investments, space acts as a vector for various actors, public and private, to gather greater political influence and security functions. With specific reference to the EO sector, the ability to acquire, process and distribute geospatial data with high frequency and precision (end-to-end) directly affects the decision-making autonomy of a State. In fact, governance choices, procurement models and, above all, the rules of access and dissemination of the products collected by the various satellites, determine strategic effects that, although through comparable EO systems, may differ in the result. In other words, a fundamental role is not only played by "what the satellite observes" but moreover on what constraints are linked to the ability to integrate the various data collected with other information flows.

Within this scenario, the role played by Italy (through the specific analysis of IRIDE) combines a strong European integration with a desire to increase national resilience for strategic sectors. The chapter will therefore try to reconstruct the dynamics of the various main state actors in space and, secondly, the Italian role through an analysis of its history in space activities, its involvement in international superstructures and the development of its space supply chain. From this point of view, the comparative analysis of IRIDE with two important EO systems – WorldView-Legion and Gaofen – will try to outline the geopolitical value that the constellation can assume.

3.1 Space as a Geopolitical Domain: Brief Analysis of the Global Actors

The number of new investments in the space sector by public and private actors, as already seen in Chapter 1, seems to be destined to reach ever higher heights soon. Since the end of the past decade, "the great acceleration" of events affecting outer space activities seem to have become one of the most effective keys to defining the new international trends for reshaping technology and for the new configuration of the global economy (Gili & ISPI, 2024). The possible interpretations, however, are not limited to a purely economic/technological scenario. The new space race is also

having important repercussions in the field of international relations modelling. We have seen how the role of satellites and AI is now a critical element in ensuring basic daily activities and how, at the same time, the recent armed conflicts in Ukraine and the Middle East have made it even more crucial in crisis scenarios. The correlation between the main factors that characterize and shape geopolitics on planet earth and the increase in investments in new technologies and activities in outer space seems to have become more crucial than ever. In other words, space activities have become a critical dimension of power, influence, and strength for the security and defense of many countries and are a key factor in the contemporary geopolitical arena (Camargo & Corrêa de Souza, 2025). It is correct, therefore, to speak of "Space Geopolitcs" as an active element in the architecture of new strategies in the international arena.

New competitions, new players and new tensions could, at the same time, undermine the prospects for a full deployment of the space economy's potential (Gili & ISPI, 2024). Although new alliances in the space domain have been established in recent years, it is possible to identify the creation of two main blocs of nations competing in the current space scenario: the "Western block" and the "Chinese-led one". These two blocs faithfully reflect the terrestrial geopolitical dynamics, nevertheless, regarding space activities, the various states seem to want to obtain their own strategic advantage both over their main competitors and at the expense of their allies. New discoveries, correlated with the use of new technologies, may create new dependencies on the part of developing countries in terms of both technology and political influence in close terms. Yet, for many decades, space had represented one of the few fields of collaboration between the various states. In 1975, the "Apollo-Soyuz Test Project" (ASTP) program represented the birth of what is commonly called "Space Diplomacy" (Sopelsa, 2025), a new use of space no longer merely a battleground between the two superpowers of the time but, rather, as a diplomatic channel, an instrument of foreign policy and international relations (Ibid.). The culmination of global cooperation in space between the various states is certainly the International Space Station (ISS) project, the result of the collaboration between five space agencies – United States, Russia, Europe, Japan and Canada – for a total of 14 different nations (Italian Space Agency, n.d.), represents "the most important and ambitious global cooperation programme in the scientific and technological field and can be regarded as the biggest engineering work ever completed by man" (Ibid.). Since November 2000, the ISS has guaranteed a continuous human presence in LEO, hosting more than 250 astronauts from 20 different countries (including at least one American astronaut). Although the operation of the ISS has facilitated more than 3,600 researchers to conduct more than 2,500 experiments (Howell, 2025), NASA has announced the end of space station operations with a re-orbiting plan scheduled for 2031. New public and private

commercial stations will replace the ISS, making the climate of mistrust and competition between the various states in recent times even more evident.

Before going into the list of programs, objectives, investments and possible aspirations of the main protagonists of the new Space Race, some methodological premises are considered necessary.

1. The speed with which we see the emergence of new crisis scenarios, new armed conflicts and situations of political instability makes it increasingly difficult to outline with certainty objectives, programs and investments in the space domain by states. Strategic volatility and sudden shocks on the international landscape shape the rapid change in security priorities that can change radically in a short period of time. This particularly affects space programs, where the technical processes and the final construction times of the various works are long and articulated. Not only that. The growing centrality of the private sector in space activities could affect the actions of governments, dependent on private capabilities, subject to market constraints and individual choices typical of companies.

2. In particular, the Trump administration's repeated pressure on the US's historical allies, its possible commercial and political disengagement with the European Union and the Atlantic Alliance (NATO), makes it more difficult to outline a precise picture even in the space sector. In this context, new fears dictated by the uncertainty of US political choices are making a concrete contribution to the new orientation of European choices towards infrastructures (national and EU) capable of guaranteeing greater resilience and decision-making autonomy.

3. In the Chinese case, the difficulty of reliably reconstructing space policies is influenced by the difficulty in transparently finding information about it. The main policy document regarding the objectives of China's space programs is the white paper published annually by Beijing, in which the general and cooperative objectives are presented.

3.1.1 United States of America

The national interest in ensuring continuity of investment in the space sector makes the United States the main player in the contemporary landscape that most clearly integrates space as a critical infrastructure and as a strategic domain. Space activities have stimulated and contributed to the improvement, since the first Apollo mission of critical priorities for the country's development. As listed within the 2020 "National Space Policy", space capabilities have been crucial "to stimulate economic growth, enhance the quality of life for all Americans and people around the world, and advance the principles of democracy, human rights, and economic freedom" (The White House, 2020). Recently, US plans in space have been marked by an increasing focus on the long-term political-strategic dimension. American superiority in space is considered as "a measure of national vision and willpower" made possible thanks to the development of American technologies that will give "a substantially contribution to the Nation's strength, security, and prosperity" (White House, 2025). The priorities listed in the December 2025 Executive Orders "Ensuring American Space Superiority", further highlight the US desire to establish itself as a world leader in space dominance (Ibid.).

On an institutional level, US space power is the result of the combination of several main players. As we have seen, the top decision-making resides in the hands of the President of the United States, who through the "National Space Council" (NSpC), coordinates national policy and supervises the work of space agencies so that they operate in line with presidential priorities and objectives. The National Aeronautics and Space Administration (NASA) leads the civilian and scientific dimension. Today, the main goal of the agency is the completion of the "Artemis Programme". The Artemis Program represents NASA's initiative to establish a sustainable and permanent human presence on the Moon, from which the technological foundations can be laid for future landing programs on Mars. By April 2026, the Artemis II mission will take four astronauts on a lunar flyby, bringing back a human presence in the deep sea after more than fifty years. The program is the result of international collaboration between 60 countries, at the time of writing, but the current architecture of the program could undergo a radical transformation dictated by the new diktats of President Donald Trump. Finally, the Artemis Program could help reduce the risks associated with dual-use technologies by increasing transparency on U.S. capabilities and operations in cislunar space and on the lunar surface (Gili & ISPI, 2024) through new tools such as uncertainty mitigation mechanisms: by making objectives, operating procedures and cooperation practices more readable, they can limit the

likelihood of miscalculation and inadvertent escalation, in particular in the competitive relationship between the United States and China.

In parallel, the national security dimension is coordinated by the U.S. Space Force (USSF), a branch of the U.S. Department of Defense. The USSF was established on December 20, 2019, as the result of the recognition of the importance of space to ensure national security, through the recruitment and training of qualified personnel, and the securing of operations conducted by NASA and commercial space launches. Its establishment, from a political point of view, marks an important step in the geopolitical field as, in fact, the vision of space is also formalized as a space of deterrence, defense and as a possible military field.

A third pole is the growing weight of the private commercial ecosystem, which no longer operates as a supplier to the United States government but as an integrated player in the various space programs. Through the establishment of the "DoD Commercial Space Integration Strategy" (2024), "commercial integration" is institutionalized and integrated into defense mission planning, through four guidelines – balancing, interoperability, resilience and responsible conduct (U.S. Department of Defense, 2024). As seen above, this new dynamic produces a double effect: if on the one hand the innovation of new technologies and the speed of technological refresh typical of market logics are absorbed into the security posture, on the other hand dependencies (also through new governance constraints) on private operators increase.

Finally, the United States is the nation that has the most developed and advanced satellite system for EO in the world. The US System is based on the synergy between civilian agencies (NASA, NOAA, USGS) and military apparatuses (DoD, NRO) which, since the first Landsat program, coordinate the various activities. Its high-resolution EO system is dominated by the satellites Worldview-1 (0.5 m resolution), Worldview-2 (0.46 m), Worldview-3 (0.31 m), WorldView-4 (0.31 m) and GeoEye (0.41 m), in which the highest resolution can be finer than 0.3m, and the observation area in a single day can reach 300 km2 (Li et al., 2021). New activities and new constellations are linked to the growth of the private sector in the sector: Planet Labs, Maxar Technologies, BlackSky and Capella Space have created constellations of small satellites with optical PLs and radars over time.

3.1.2 China

In just thirty years, China has become one of the top space powers, replacing Russia as the main rival of the United States. There is still an important gap between the two states, but China can boast some unique achievements. This progress in the space sector has been possible thanks to the transformation of its space program from a simple technologically imitative initiative to an autonomous, ambitious enterprise, with the aim of achieving world leadership by 2050 (ANSA, 2024). At the heart of China's projects is the "Chang'e" space program, which began as early as 2007 with the first launch of Chang'e 1, an orbital probe designed to map the lunar surface. Of particular importance is the Chang'e 4 mission. Indeed, in 2019, China achieved its first "world first" by landing on the far side of the moon with the Chang'e 4 mission (Gili & ISPI, 2024).

The exploration of the "dark side of the moon" represented a milestone in space exploration due to the impossibility of transmitting radio signals directly to Earth due to the synchronous rotation of the Moon. Through the launch of the "Quequiao" satellite, positioned at the Earth-Moon L2 Lagrange point, China has managed to build a radio link between Earth and missions on the far side of the Moon, making remote control and data transmission possible (Xin, 2019). The use of the Lagrange point represents not only a technical/technological success: just like the conquest of strategic points on Earth, but the control of the point also represents an important step in the definition of the new Space Geopolitics. Many analysts agree that the Chinese lunar program may also hide a function of legitimizing the regime and projecting global soft power, linked to the importance and use of Lagrange points also as platforms for space surveillance, the positioning of satellites and, in the future, possible military or civilian outposts (Kaplan, 2020).

The construction of the "Heavenly Palace", the Chinese Tiangong Space Station, represents another fundamental event for the development of the Chinese space program. Unlike the ISS, the Tiangong Station is an independent and fully Chinese-managed project, consisting of three modules: "*Tianhe*" the central and habitation module for astronauts, launched in 2021, "*Wentian*" an experimental module launched in 2022, and "*Mengtian*" the final laboratory operations module, launched in 2022. The station hosts astronauts on a rotating basis for periods of about six months and performs experiments in areas such as biology, physics, astronomy and space medicine. Its activity is not only an operational orbital platform but serves as an "orbital precursor" for more ambitious goals of the Chinese program: the construction of a robotic lunar base by 2035 and further missions for the

in-situ exploitation of resources, to acquire a dominant position in extraterrestrial resources (Autry & Navarro, 2024).

On December 2025, the newly formed Institute of Radio Spectrum Utilisation and Technological Innovation in China filed proposals for two satellite constellations, the CTC-1 and the CTC-2, with the International Telecommunications Union (ITU), the UN body that allocates spectrum in space. Each of the two constellations contains 96,714 satellites, for a total of about 200,000 new satellites, which if completed would represent "the largest assembly of satellites ever put in orbit and would effectively lock competitors out of a region of LEO" (Hunter, 2026).

Given the difficulty in a collaboration with the West bloc and with the European countries, China is looking for new forms of cooperation with developing countries, the "Global South". If one of the first objectives set out in the White Paper "China's Space Activities in 2021" is to "use outer space peacefully, maintain outer space security, promote the construction of a community with a shared future for mankind in the field of outer space and benefit all mankind" (State Council Information Office of the People's Republic of China, 2022), in support of this human-centric narrative, China needs new international allies and partners. For this reason, the global "Belt and Road Initiative" (BRI) program was extended to the space domain in 2016 with the "BRI Space Information Corridor" (BRISIC) (Gili & ISPI, 2024), with the main objective of providing products and services to countries along the Road, open new markets to the Chinese space industry, and promote development and people-topeople exchange (Ibid.). China's space cooperation focuses on two approaches: providing space services and selling space assets.

Over the past two decades, China has managed to create one of the most comprehensive and competitive EO architectures in the world. The "China High-Resolution Earth Observation" (CHEOS) project aims to improve China's observation capability of all-weather, all-time, and global coverage (Li, Wang, and Jiang, 2021). To improve China's remote sensing technology and to satisfy the increasing remote sensing data requirement from economic and social, applicational, a technical program, namely "Gaofen", was kicked off in 2011. "Gaofen" means high-resolution in Chinese, which refers to realizing high spatial-spectral-temporal resolution observation of the Earth. The development of the EO's sector in China might has a later start than other major EO programs in US and Europe but Beijing has made remarkable strides in narrowing the technological and temporal gap with foreign countries.

3.1.3 India

In recent years, India has been establishing itself as a new player in the global space scenario. The "strategic delay" towards its competitors is now overcome, thanks to technological self-sufficiency and a vision of development of the national sector. India, in fact, is developing an autonomous industrial capacity (Rajagopalan & Stroikos, 2024) that allows it to diversify its space activities: from strengthening the EO and satellite navigation constellations (IRNSS and NavIC), to engaging in new interplanetary missions. A further factor that has contributed to the country's progress in the space sector is the strengthening of its bilateral collaborations, through specific agreements with the United States, France, Japan and Australia (Ibid.), thanks to the proactive role of the Indian Space Research Organization (ISRO), which is now considered an example of efficiency and low-cost innovation. The country's geopolitical proactivity has allowed it to extend Indian influence to Asia and Africa as well, through the launch of satellites for developing countries (Ibid.). For India, too, space is not only a field of scientific development. In the Def Tech 2023 on "India's Aerospace Capabilities And Technology Requirements" in March 2023, Indian Air Force (IAF) Chief, Air Chief Marshal V. R. Chaudhari stated that India has to "develop both offensive and defensive space capabilities to safeguard our assets" (Pandit, 2023). He added that "the race to weaponise space has already started and the day is not far away when our next war could spread across all domains of land, sea, air, cyber and space. We need to capitalise on our initial successes in space and prepare ourselves for the future" (Ibid.). Thus, India's priorities about outer space are being reshaped. As already highlighted in Chapter 1, India has become the fifth country capable of developing ASAT technology, highlighting how India's strategic vision considers space as a fundamental tool in ensuring security for the country and how New Delhi's vision is moving from a morality-based approach to one that is driven by pragmatism and national security considerations (Gili & ISPI, 2024).

Since 2020, India has embarked on a process of liberalization of the space sector market, in order to ensure greater participation of private players in the sector. This paradigm shift represented a historic turning point for the country. Thanks to the creation of IN-SPACe (Indian National Space Promotion and Authorization Center), established in 2020, the role historically dominated by ISRO is flanked by a new regulatory body that acts as an intermediary between ISRO and commercial

operators. The new body ensures more transparency, fairer access to infrastructure, and separation between the state's operational and regulatory functions (Gopalakrishnan & Rishiraj, 2022).

3.1.4 Russia

The first country to have successfully completed the launch of the first satellite into orbit, Sputnik, and to have sent the first man into space, Yuri Gagarin, is now undergoing a profound change in geopolitical and strategic terms of space. The Russian civil and commercial space sector has suffered a setback over the first two decades of the XXI century (Gili & ISPI, 2024), two to many factors and many events that have conditioned and redefined its role as the main antagonist of the United States in space. If in the post-WWII period the Soviet space sector had managed to attract the best and brightest of Russian talent and significant infrastructure investment (McClintock, 2017), the collapse of the former Soviet Union drastically reduced government funding shortages, causing drastic repercussions to the entire Russian space sector. The lack of funding caused degradation to

1990 Orbital Launches	2000 Orbital Launches	2010 Orbital Launches	2022 Orbital Launches
75	37	30	22

Figure 12: Total Russia's launches since 1990. (Source: Aerospace Security, 2023)

national constellations, infrastructure, personnel and, moreover, delays in accomplishing new projects (Ibid.). In 2005, with the new strategic space plan, Putin tried to relaunch Russia's overall space ambitions, but the 2008-09 global financial crisis and the sanctions against the country after the invasion of Ukraine in 2014, led to new crucial impacts on the country's commercial and space activities. Further, the new full-scale invasion of Ukraine in February 2022 has amplified this already complicated situation. The decline in the number of orbital launches completed by the Russian Federation from 1990 until 2022(Table 4), highlights Moscow's difficulty in operating in outer space, due to a long-term, contractual, launch embargo on nearly 200 Russian civil-space and commercial satellites (Grunert, 2022).

If the civil and commercial sector of the space sector has had an evident decline compared to the times of the Cold War, the Russian military space sector charted a different course. Putin has never

hide his ambitious to use outer space as a military asset and, with China, Russia worked to limit the US in space through treaty proposals like the Prevention of Placement of Weapons in Outer Space Treaty (PPWT), with drafts presented in 2002 and several times thereafter (United Nations Office for Disarmament Affairs, 2014). Russia demonstrated advances in military space capabilities. For example, in 2019 and 2020, the country unashamedly tested prototype space weapons, soliciting protests from the United States and others (Gili & ISPI, 2024) and, in 2021, Russia tested ASAT weapon generated more than 1.500 pieces of trackable debris.

3.1.5 Europe

The European space industry developed and supported by the ESA, thanks to a strong mandate in industrial policy (Article VII of the ESA Convention), it is facing a phase of profound transformation in its space strategy, dictated by the rapid change in its international relations and the global geopolitical context. While the war in Ukraine has had direct consequences on the European space program, causing the suspension of the "Soyuz" launches and the freezing of the "ExoMars" mission in collaboration with Roscosmos, the choices dictated by the Trump administration have led to a repositioning of Europe and its role in space. Despite numerous achievements and success in certain domains of choice, which prove that Europe is capable of leadership, the continent today does not meet the requirements to be a space power – an "entity with the means to autonomously deploy, operate and benefit from any space-related capability to support the achievement of national objectives that it has autonomously determined" (Alberti, 2023).

The path towards real European spatial sovereignty develops within a fragmented system of financing and governance, significantly more articulated than the monolithic models of China or the United States. The European space budget is distributed through the European Commission (policies and funding), ESA, the EU Agency for the Space Programme (EUSPA), EUMETSAT (meteorological observation) and defensive actors such as DG DEFIS and EDA. A complex mechanism that, although designed to encourage specialization, actually slows down the operations and industrial efficiency of the sector. In addition, the principle of geo-return applied in the programs developed by ESA, provides for a distribution of industrial contracts proportional to the financial contributions of the member states. A mechanism that discourages the technological meritocracy of the various states and weakens the international competitiveness of European companies (Ibid.).

The main problem within the EU's strategic vision of space is the concrete actions of its main actors. France, Italy and Germany seem to prefer a national route, bilateral agreements and strategic support to their industries in the sector, rather than fully merging into an integrated strategy at European level. On the industrial front, the recent MoU between French and Italian private companies, Airbus Space & Defense, Leonardo and TASI (Project BROMO), will lead to the creation of a new European joint venture to produce satellites capable of competing with American and Chinese international competitors. Although the agreement marks an important step in bridging the gap with global competitors, doubts arise about the role of the European space industry tout court and its possible threat to the idea of business in space, as stated by the President of OHB Fuchs (Martino, 2025). Finally, the new "Space Shield" plan, scheduled for 2026, should in theory constitute a unified response to strategic risks and hybrid threats, but its implementation will depend on the political willingness of member states to cede portions of operational sovereignty and to harmonize their respective industrial policies.

3.2 Italy's role in Space

Since the beginning of the "Space Race", in a context where the two superpowers of the time (U.S.S.R. and U.S.A.) confronted each other in the midst of the Cold War also on the space domain, Italy has managed to play a role of "unprecedented protagonist" among the other nations involved. Its role as an "early adopter" in space activities has allowed it to establish itself on the world scene and to emerge, in particular, as one of the most important European countries in the sector. The data of the last European ministerial dedicated to space, hosted in Bremen, confirm this: through the commitment of a contribution of 3.5 billion euros, equal to 15.79% of the entire budget, for the next three years, Italy settles among the top three European contributors, together with Germany and France respectively (ASI, 2025). His activity, as mentioned, has deep and consolidated roots. Although it did not have an aerospace industry comparable to the Soviet and American ones, nor its own nuclear arsenal, the Italian contribution since the sixties was surprisingly structured and visionary. According to economic data, in 2023 Italy was in sixth position globally in terms of space spending to GDP ratio. An early participant in orbital activities, Italy has steadfastly linked its identity to space activities (AGI, 2023). Over the years, the nation has refined this identity through strategic policies, robust programmes, and high-quality industrial players. Domestic governance along with

Italy's standing on the global stage received a significant boost with the establishment of the Italian Space Agency (ASI) in 1988 (Gili & ISPI, 2024).

3.2.1 San Marco Project

On December 15, 1964, La Sapienza University of Rome launched the first satellite of the San Marco series, designed and built in Italy, from the NASA base in Wallops Islands. From that moment, our country's adventure in Space began: a path that still contributes today to confirming Italy in the ranks of industrialized nations (Spagnulo, 2019). Italy became the third nation in the world to launch its own satellite, *San Marco 1*, an extraordinary achievement that demonstrated the ability of a medium-sized nation to compete in space. Although both the British and the Canadians preceded the *San Marco 1* with the launch of their *Ariel* and *Alouette* satellites, the construction of these two, however, was significantly supported by the US industry. The Italian project, on the other hand, was designed and built in the offices of "Via Eudossiana" and "Via Salaria" in Rome, where the recently renovated test facilities can still be visited (Ibidem). This goal would not have been possible if not for the vision and determination of Professor Luigi Broglio, considered the "father of the Italian space program", the same fraudster who a few years earlier, in collaboration with the Italian Air Force, had created the "Aerospace Research Center" (CRA) in 1956. Aware that Italy could not afford such a program autarkically, Broglio supported cooperation with the United States and with the support of the government of Amintore Fanfani in 1962 a memorandum of understanding was signed between the CNR, the CRS and NASA, so that future Italian satellites would be launched by American Scout rockets. The protocol then became an official partnership between governments with the signing in Rome between Foreign Minister Attilio Piccioni and US Vice President Lyndon Johnson, and the consequent Italian allocation of 4.5 billion lire over three years with a special law (Ibidem). The partnership with the United States provided not only the Scout launcher for launch, but also crucial technical and logistical expertise (Ministry of Economic Development, 2020).

A key factor in the success of the *San Marco* project series was the use of an innovative maritime platform, located off the coast of Kenya, near Malindi. This structure, *San Marco Equatorial Range*, allowed launches to be carried out near the equator, optimizing the energy efficiency and trajectory of the satellites (ESA, 2023). The structure's ideal position for launching satellites into orbit

allowed the centre to become an international reference point for space research and operations, a symbol of Italy's innovative and pragmatic approach.

The San Marco 1 satellite was designed to collect fundamental data on atmospheric density and ionosphere characteristics, providing essential information for the development of future satellite communication and space weather technologies (Broglio et al., 1965). The success of the experiment ushered in a new era in understanding the interactions between the upper atmosphere and satellite orbits, anticipating many of the challenges faced in subsequent space missions. The success of the San Marco program was not limited to scientific results: it pioneered numerous subsequent collaborations such as ESA and other global organizations, representing a turning point for Italy, consolidating its international reputation. The maritime platform continued to be used for several decades, supporting further launches and experiments (Istituto Affari Internazionali, 2023).

3.2.2 ESA and International Partnerships

Italy has played and continues to play a central role also within the field of international space cooperation. While the country's first attempt at international cooperation in space matters was in 1958, when Italy joined the "Committee on the Peaceful Uses of Outer Space" (COPUOS) (United Nations General Assembly, 1958), today Italy is involved in more than 40 bilateral, multilateral, international agreements and MoU in the space sector. A fundamental step was the ratification, in 1967, of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (OST). In addition to the OST, the international legal framework in space also includes the Convention on Registration of Objects Launched into Outer Space, the Convention on International Liability for Damage Caused by Space Objects, the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, and the Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Istituto Affari Internazionali, 2023). Among these five agreements, Italy ratified the first four, renouncing the ratification of the last one, also known "Moon Agreement", aligning themselves with a large group of states that demanded less subordination and greater freedom in the use of celestial bodies. Instead of the "Moon Agreement", Italy was among the first eight countries to joined in 2020 the NASA's campaign "Artemis", actively contributing to the development

of the Lunar Gateway, the outline of the Moon-Mars exploration strategy and the European Service Module. The historic partnership between Rome and Washington has also led to a further agreement that allows Italy to conduct experiments directly on the ISS in the fields of medicine, physics and biology.

In 1975, Italy was among the founding countries of ESA and from the beginning has contributed incisively to the definition of the priorities of the European agency. The collaboration between ASI and ESA has contributed over the years to the development of numerous space programs also in the field of EO, of particular interest for the present paper. The Earth Observation segment represents one of the areas in which Italy has expressed its best technical-industrial capabilities, through a high-level industrial supply chain and the development of cutting-edge technologies. Although, as seen above, the gap with international competitors is evident, the EU through various EO programmes have tried to create an independent European capacity for the orbital monitoring for both technical and geopolitical goals. As highlighted by Gili & ISPI (2024), Italy has strategically invested in every segment of the space sector, with a special emphasis on Earth observation technologies featuring dual-use and dedicated capabilities that are regularly updated and upgraded (Gili & ISPI, 2024). Since the 1990s, the European Remote Sensing (ERS), Envisat and, more recently, the Copernicus programme have been the three key milestones for this purpose.

1. **ERS**: launched in 1991, ERS-1, followed by the launch in 1995 of its twin ERS-2, was the first European satellite in the field of EO. Developed and operated by ESA, the two satellites featured advanced capabilities for the time, including SAR radar, radar altimeters and microwave radiometers. Italy actively participated both in the financing of the program and in the construction of key subsystems, thanks to the commitment of companies such as Officine Galileo and Telespazio, which contributed to the development of optical payloads and the ground segment for data acquisition (ESA, 1999). The various activities of the two ERS satellites, through their monitoring of European soil and, in particular, of oceans, ice, land surfaces and climate variations, has laid the foundations for today's common civil and scientific applications, such as sea level monitoring or landslide analysis. Italy's contribution was also fundamental in the downstream segment, with the development of data processing infrastructures, such as the acquisition centres in Matera and Fucino.

1. **Envisat**: in 2002, Italy participated in the ESA Envisat programme, the largest and most complex environmental satellite ever built up to that time. The mission intended to continue and improve upon measurements initiated by ERS-1 and ERS-2, and to take into account the requirements related to the global study and monitoring of the environment (ESA, 2013). Equipped with ten scientific instruments, including radar, spectrometers and radiometers, the primary objectives of the Envisat mission was in continuity for the EO activities started with ERS, like the monitoring of the atmosphere, the earth's surface, the oceans and the polar ice, providing data on air pollutants, deforestation, ocean dynamics and climate change. Italy was one of the main contributors to the project through the development of various optical instruments (MERIS – Medium Resolution Imaging Spectrometer), as well as managing a significant share of the downstream segment through ASI and its infrastructures (Ibid.). Envisat data were crucial for the development of predictive models and tools for environmental and geospatial decision-making. The mission was interrupted in 2012, due to the unexpected loss of contact with the satellite, but still represents a reference point for subsequent multi-sensor EO missions.

2. **Copernicus**: previously known as GMES (Global Monitoring for Environment and Security), Copernicus is the European Union's EO active programme (European Commission, n.d.). Launched in 2014 as a joint programme of the European Commission and ESA, Copernicus represents the European effort to create an operational system capable of collecting a comprehensive set of parameters to help us check the health of our planet, and identify, respond and adapt to global phenomena (Jutz & Milagro-Pérez, 2020). Based on a constellation of Sentinel satellites (SAR, multispectral, altimetry, atmospheric) and a network of ground-based services and data, Copernicus provides free and continuous access to global data, useful for environmental, civil protection, security and resource management applications. Italy is among the main industrially involved countries: Leonardo and Thales Alenia Space Italia have contributed to the development of Sentinel-1 (SAR radar) and Sentinel-3 (ocean and terrestrial observation), while Telespazio is a leader in downstream services and data processing (European Commission, 2023). The ASI center in Matera is one of the European nodes for the acquisition and distribution of Copernicus data and hosts the Italian PDGS (Payload Data Ground Segment). The synergy between ASI, industry and scientific institutions has allowed the country to rank among the main technological and economic beneficiaries of the program. In addition, Copernicus data are integrated into

multiple public policies, from agriculture to hydrogeological risk management, to civil defence support and urban planning. Italy's position is further strengthened by its participation in the development of the second-generation Sentinel, with completion expected by 2028, which will integrate hyperspectral capabilities, thermal infrared and new radar bands.

In April 2023, Italy also became the thirteenth country to commit not to conduct direct-ascent anti-satellite (DA-ASAT) tests after having signed the resolution on destructive direct-ascent anti-satellite missile testing passed in 2022 by the UN General Assembly (Istituto Affari Internazionali, 2023). If the DA-ASAT commitment has represented one of the most important act for the de-militarization of space by the international community, on the other side Italy is actively involved in the main initiatives promoted by the EU in the defence field that have also space implications, in particular the Permanent Structured Cooperation (PESCO) and the European Defence Fund (EDF) (Ibid.). Within the PESCO framework, Italy led the European Military Space Surveillance Awareness Network (EU-SSA-N) project, aimed at developing an autonomous and interoperable military Space Situational Awareness (SSA) capability compared to the US model (Permanent Structured Cooperation, n.d.).

3.3 IRIDE in the International Context: Comparisons with Similar Structures

In the previous paragraphs, we have tried to provide parameters, although not exhaustive in all their components, of the activities, possible ambitions and geopolitical positioning of the major powers involved nowadays in the various activities inherent in outer space. The United States and China (effectively taking over from Russia) are, to date, the main superpowers also in the space domain. While the United States can boast of a dominant position since the beginning of the first space activities, with a significant delay China is trying to fill the gap. Two new massive dual-use satellite constellations, CTC-1 and CTC-2, totalling the record of almost 200.000 satellites (96.174 satellites each), represent the new China application to dwarf SpaceX ambition (Hunter, 2026) and will focus on "Low-altitude electromagnetic space security, integrated security defence systems, electromagnetic space security assessment of airspace, and low-altitude airspace safety supervision services", a similar role to the SpaceX Starshield satellites (Ibid.).

As seen in chapters 1 and 2, the fundamental role played by the development of new dual-use constellations and the integration of AI systems have become crucial factors for the affirmation of space actors, public or private. New technologies that have become necessary and strategic not only for economic and technological progress but also fundamental for the acquisition of new geopolitical influence. In the global landscape of EO activities, EO satellites, together with telecommunications satellites, constitute the ideal strategic infrastructures for dual-use applications and for the integration of AI systems. We have seen how they allow, through end-to-end systems, the collection, processing and distribution of fundamental data facilitated by AI systems, in its ML and DL derivations, for a multiplicity of sectors: from the management of climate crises to environmental security, up to intelligence and security actions. It can therefore be deduced that the autonomous ability to cover the entire chain of EO activities - from design to the management and processing of the acquired data - represents a key index of technological sovereignty and international competitiveness.

In this context, IRIDE is prefigured as a key project of the new Italian space strategy. If the implementation deadlines are respected, if its six sub-constellations are fully operational and integrated with their central infrastructure, IRIDE intends to place itself among the EO infrastructures with the best capabilities in use today in the world. Its technical characteristics and the technologies adopted for the various PL (Appendix A: Technical Specifications of IRIDE Sub-Constellations) are in line with the global trend towards the convergence of high-resolution multi-source data. For a further understanding of the possible capabilities of the new Italian constellation, it is therefore necessary to adopt a comparative reflection with some of the other main EO systems globally. As already specified in section 2.2, this paper does not intend to compare IRIDE in purely technical terms, belonging to a typically engineering field of study, but on the possible impacts, advantages and disadvantages, potential risks and dual-use capabilities of the infrastructures compared.

3.3.1 Methodological Note

The present analysis focuses on the comparison between the new IRIDE constellation and two of the main international EO architectures: WorldView-Legion by Maxar Technologies (U.S.A.) and Gaofen/CHEOS (China). For the comparison, an institutional and geopolitical perspective is adopted,

based on the selection of four survey criteria, listed below, to try to grasp and explain the political and strategic value that IRIDE may assume.

1. **Infrastructure governance**: to evaluate the management, coordination models and financing methods of the system (national or federated, centralized or polycentric, public or public-private).

2. **Data accessibility**: to assess the varying degrees of accessibility of the data collected for different public, private or scientific users. The positioning gap between the comparative infrastructures can be found within the open data vs selective control paradigm.

3. **Dual-use capability**: to evaluate possible uses in the civil or military field. This section will have a further confidential in-depth analysis.

4. **Geopolitical and diplomatic value**: to measure the use of the various EO systems as possible tools for influencing international relations between states (soft and hard power), intergovernmental cooperation and positioning in global technological coalitions.

The qualitative-comparative approach is based on the analysis of institutional sources, scientific literature and strategic documents to evaluate the transformative potential of IRIDE and its possible impact for Italy and Europe. For the evaluation of the dual-use capability of the various systems, the quantitative approach analyzed in Conte's work (2025) completes the synergistic analysis between EO's systems and dual-use capabilities, with a scaling that varies between 0 (purely civil application) to 1 (purely militar). Table 5 summarizes the various scores achieved by the various PL on board EO's satellites, useful for providing (although not representing an official index) an interpretative key to the potential dual-use average degree of the various constellations through the technologies they use.

Detailed Purpose	Score
Optical/Multi-spectral Imaging	0.50
Hyperspectral Imaging	0.55
Infrared (IR)	0.60
SAR (Synthetic Aperture Radar)	0.70
RF (Signal-based Observation)	0.65
Video Imaging	0.55
Meteorology	0.35
Earth Science	0.20
ISR (Intelligence, Surveillance, Reconnaissance)	0.85

Table 5: Detailed Purpose and Dual-Use Score for Earth Observation Satellites (Source: Conte, 2025)

3.3.2 IRIDE vs WorldView-Legion

WorldView-Legion is an American commercial constellation consisting of six very high-resolution imaging satellites from Vantor, a rebranding of Maxar Intelligence department specialized in Spatial Intelligence. Operating alongside the existing WorldView-1 to WorldView-4 satellites, WorldView Legion provides 34 cm panchromatic imagery and 1.36 m 8-band multispectral imagery, designed to provide up to 15 revisits per day, depending on location, allowing multiple images of the same location to be captured throughout the day (European Space Agency, n.d.). Maxar has declared that the addition of the new satellites to the former constellation allow now a full coverage of the world's most populated areas from "dawn-to-dusk" (Hitchens, 2024). Its ability to collect 30 cm class imagery, with more than 5 million square kilometres collected per day, make it one of the most cutting-edge EO's infrastructures in the world. On an industrial level, through its various products, Maxar Technologies operates according to a market-driven logic of a private nature but an integral and structural part of the current US information supply chain. The governance of the constellation, in fact, represents an emblematic case of integrated governance between public and private: the ownership structure and activities related to the operation of WorldView-Legion services are private and managed by Vantor, but a significant share of the demand for the services offered is government through "Electro-Optical Commercial Layer" (EOCL) contracts with which NRO purchases the

rights to commercial electro-optical satellite images on a multi-year basis of private providers (NRO, 2022). Specifically, Maxar was awarded, through an EOCL of a five-year base contract with five additional years of options through 2032, the “largest ever commercial imagery acquisition contract awarded by the NRO (Maxar, 2022). In fact, the state, while not owning the ownership rights of the constellation, manages to influence its ecosystem through procurement, licensing regimes and integration into the flows of the defense-intelligence community. If IRIDE operates through a logic of public governance, “public first”, since its conception, WorldView-Legion is part of the “commercial first” segment but with a strategic operation commissioned through public procurement.

As a result, the US government is the first beneficiary of the data collected by the constellation, although within the “ESA Third Party Mission” perimeter, through the service provided by the European Space Imaging (EUSI), ESA offers on-demand delivery to users in ESA member states and China as part of the Dragon cooperation, of some WorldView products for the scientific and quota-based segments. subject to operating conditions (MOQs, tasking windows, minimum cloud/off-nadir constraints) and control mechanisms. These mechanisms allow the limitation or possible rejection of the various orders based on “applicable security regulations” for certain geographical areas (European Space Agency, n.d.). The dual-use character of the constellation, in fact, is well represented by the note in the ESA catalog on WorldView-Legion where it is specified that “VHR of conflict areas cannot be provided”, explaining how access to data is in fact conditioned and limited regardless of the existence of technically acquirable images (Ibid.). Susanne Hake, general manager of Maxar Intelligence, told in an interview during the annual GEOINT conference that having a mix of orbital positions allows a wider variety of imagery that can show a target from different points of view, as well as at different times (Hitchens, 2024). The geopolitical value of WorldView-Legion is functional for strategic objectives: through its ability to monitor strategic areas and the speed of mobilizing commercial data for a wide government audience, it increases the resilience and flexibility of the US national architecture. In the comparison with IRIDE, the geopolitical dimension of constellations is not simply reduced to the owner of the constellation and its governance but, rather, concerns in particular the accessibility of the data and the rules of its sharing. “Unclassified” data acquired via VHR enjoys a more streamlined autonomy for sharing than images classified as “government”. Finally, the indirect governance of the US government can maintain exclusive control mechanisms for exceptional situations. According to Hitchens (2021), some discussions on the contractual terms used by the NRO would reveal clauses that would allow, in cases approved at the highest levels, a form of temporary “exclusive access” on specific

areas/periods, a concept that indicates the possibility of reducing availability to third parties in circumstances considered critical (Hitchens, 2021).

3.3.3 IRIDE vs Gaofen (CHEOS)

Among the most strategically relevant Earth observation models globally, the Gaofen (GF) constellation, the heart of the Chinese CHEOS program, offers a significant reference for understanding the evolution of EO capabilities from a geopolitical point of view. The term Gaofen (高分, literally "high resolution") refers to a family of Earth observation satellites as one of the largest strategic projects defined in the framework of China's S&T development priorities that aims to build a high spatial, temporal and spectral resolution observation capacity, thus seeking to ensure "all-weather" coverage of the Earth's surface. all-time, global". The peculiarity of the Gaofen constellation, more generally of the entire CHEOS program, lies in the various integrated orbits in which the constellation operates. Unlike IRIDE focused on LEO orbit, GF is designed as a multi-platform ecosystem operating on multiple orbits. Like IRIDE, CHEOS is an end-to-end system in which the operations of satellites in orbit are integrated by the downstream segment in which data reception and processing infrastructures transform them into usable services.

CHEOS is structured according to a highly centralized state-military paradigm, reflecting China's view of space as a critical domain for national security, territory control, and information asymmetry. If IRIDE presents a hybrid governance system through the two agencies ASI and ESA, the centralization of governance directly in the hands of the Chinese government makes it a strategic system with a single management. As a domino effect, the accessibility of GF's data is given by the Chinese government's willingness to disseminate the various data acquired, making it a model that is difficult to access. In November 2019 the CNSA rolled out a platform for the sharing of data collected by 16m multispectral cameras of the GF EO satellites (CNSA, 2019) but this openness does not equate to an unconstrained availability of the data collected by GF. The dual-use nature of the program, as explained in Li's work (2022), also sees national strategic needs, including the defense field, as the ultimate goal. It is assumed, therefore, that the most sensitive products remain subject to the secrecy imposed by government channels. Through the link between the evolution of the Chinese remote sensing sector with national security objectives and military capabilities, it can be deduced how GF's

architecture can also support ISR capabilities (USCC, 2024). Finally, on the geopolitical side, CHEOS contributes to strengthening China's information autonomy and its ability to project influence through data infrastructures and selective cooperation. In this sense, the opening of 2019 can also be read as a diplomatic tool of soft power, while maintaining substantial control over the most sensitive outputs.

3.4 Conclusion

In the last two decades, a "new spatial order" has emerged in which new actors, public and private, are establishing themselves within the spatial domain. China and India have joined (in the Chinese case replaced) Russia's race as a historic "antagonist" to the US, a race further slowed down by the Kremlin's massive military commitment in the Ukrainian conflict. If in the first two chapters, albeit with some initial introduction to the topic, we tried to list in detail the characteristics, the possible uses of EO systems and how they are fundamental today in both the civil and military fields, the Chapter tried to provide a new interpretation, expanding the capacity of EO systems also as a strategic geopolitical infrastructure. The availability of data derived from the application of the latest generation of remote sensing's technologies, their control and, above all, the ability to have an end-to-end system, determine competitive advantages over space competitors. In other words, the ability to autonomously oversee the entire value chain (acquisition-processing-distribution) of EO data is nowadays a further indicator in terms of technological sovereignty and international standing. In an international context increasingly influenced by new crisis scenarios and diplomatic closures between countries, the role of the new EO constellations acquires even more strategic value.

Within these various dynamics, Italy is placed in a peculiar and ambiguous geopolitical position. Although, as we have seen, its involvement and its technical/scientific capacity has been of the highest level since the dawn of the Space Race, today it finds itself in a position in which on the one hand it remains strongly anchored and integrated within the European space ecosystem, placing itself as the third largest financier of ESA programs and contributing through its industrial excellence to the realization of the same. On the other hand, it strengthens its own trajectory of autonomy over time, made up of increased resilience, strategic responsibility and bilateral collaborations with international partners. In this context, IRIDE emerges as a pivotal project that attempts to combine the two needs: to contribute to increasing public value through a national EO infrastructure with

technologies capable of monitoring the territory even in critical situations and to increase the current European EO architecture system through its complementarity with Copernicus. The Copernicus accessibility system has made it a global benchmark from which IRIDE has drawn inspiration. Despite this, through a comparative analysis it has been seen how the defense of the management and dissemination of data in crisis situations can represent a fundamental factor for the defense of one's national interests. The methodological note adopted made it possible to highlight how a comparable EO system can produce opposite political effects depending on who governs it and how the dissemination of the acquired data is regulated.

Although in opposing ways, it has been seen how the US and China protect sensitive data and limit its dissemination. On the one hand, the US public-private partnership has allowed Washington to establish itself as the leading power in space, through an opening of markets to private actors who have the potential to foster markets, enhance national capabilities, and reduce costs, while advancing policy objectives (Kim, 2023). A system that seems to be self-sustaining through a logic of supply / demand between the two actors that aims to strengthen the strategic interests of the country. However, the dual-use potential of the various EO systems, amplified by the adoption of AI systems, raises questions about the potential use of data by private actors. On the other hand, China's centralized state logic has been the central engine in establishing the country as the second space power. The government governance of the various projects has allowed for the rapid development of the various space infrastructures. Access to products is structurally subordinated to state priorities and to a selective management of the information collected. The 2019 opening (CNSA, 2019) highlighted how China's EO architecture can also serve as a tool for diplomacy, however, it is not possible to identify the Chinese system within an "open source" paradigm.

In Chapter 4 the ambiguities of IRIDE, typical of dual-use systems linked to possible military uses, will be analyzed in detail. The "S8 Security" segment remains a topic to be explored in several aspects: on the legislative level, through an analysis of the European AI Act, we will try to understand how some components can or cannot be adopted on board satellites, while an in-depth analysis of the nature and purpose of the funds allocated to the IRIDE project will try to outline, even more, the dual-use concept within the legislative sphere.

Chapter 4

AI, Dual-Use Governance and the Ambiguities of IRIDE

The dual-use nature of IRIDE, combined with its potential AI applications, makes the constellation a strategic infrastructure in which its EO activities are not confined to image acquisition alone. Its end-to-end configuration makes IRIDE able to cover all phases of analysis of the acquired data, positioning it, within the European legal context, in a regulatory grey area between "civil-first" purposes and "security-oriented" uses.

The chapter will try to analyze the potential ambiguities of the new Italian constellation in three different areas. In the first two, the current European regulatory structure could on the one hand create a strategic disadvantage in comparison with other international players in the sector. On the other, it can create possible risks for the security of the personal data acquired, amplified by the constellation's in-situ AI applications. Finally, the central role of the PNRR in the construction of the infrastructure will be analyzed. In particular, the dual-use nature of IRIDE raises questions about the potential activities analysed in the previous chapters and the target of the European funding after the Covid-19 pandemic.

4.1 European Regulatory Constraints on IRIDE's AI-Enabled Capabilities

The regulatory variant relating to the launch, management, operation and, more generally, relating to all IRIDE activities, includes an articulated regulatory complex. As seen above, the main regulatory source of space activities remains the OST, through which an attempt has been made to provide an international regulatory framework for the various space activities of the various states. Despite this, the willingness of public and private actors to operate in the space sector seems to follow the will of a national regulatory logic that allows it to develop more quickly and have fewer regulatory barriers. In fact, the possibility of being able to establish the criteria, principles and regulatory constraints with which to operate in space (recent geopolitical developments have shown how the issue is a crucial topic even for terrestrial activities) is part of a broader discussion that is still very heated in the dichotomy between international and state law. In the previous chapter, the various programs and possible ambitions of the main states operating in the space sector were briefly listed,

highlighting how through different plans – Chinese centralization vs. US public-private partnership – the various states have been able to establish themselves in the context of space activities.

The Italian context presents a different situation. Through the entry into force of Law 89/2025 "Provisions on the Space Economy", known in journalistic terms as the "Space Economy Bill", Italy was the first European country to adopt a framework law on the space economy (Barretta, 2025). The bill is divided into five titles:

1. **Title I** – General Provisions, sets out the aims and fundamental definitions of the various key concepts relating to space ("space activity", "space object", "space operator").

2. **Title II** – Exercise of space activities, frames the objective and subjective requirements for operating in space with the aim of increasing the inclusion of private companies through the creation of a new authorization system entrusted to ASI as national technical authority (Ibid.), also in charge of exercising supervisory activities.

3. **Title III** – Registration of space objects, which establishes a new national register for space objects launched under Italian responsibility, also managed by ASI

4. **Title IV** – Liability and insurance, Article 18 introduces strict liability of operators for damage to third parties on Earth and in flight. Liability remains even in the event of wilful misconduct or gross negligence, with rare exceptions (Ibid.). Liability also falls in the event of damage by foreign states and a minimum insurance coverage of 100 million euros per claim is imposed on operators (Ibid.).

5. **Title V** – Measures for the economy of the space, strategic objectives are defined through a new public-private synergy through the push of the State to promote new infrastructures in LEO. Finally, it is clarified that space objects registered in Italy are considered national territory also abroad (Ibid.).

Through the new regulatory framework, Italy recognizes even more the importance of the space domain in the various strategic sectors of the country, marking a turning point not only for the

national aerospace sector, but redefining a new geopolitical and industrial vision of the country. The new law has highlighted how the combination of community/national relations, the Italian role within the European context, presents different peculiarities and visions. In fact, anticipating a possible future European regulation of the sector, Italy has first established a regulatory structure on which to base. The national will to establish its own criteria and principles on which to base new space activities reaffirms on the one hand the country's desire to develop its own autonomous capacity in the space field and, on the other, the intention to fill the European regulatory gap while waiting for a common direction, while helping to guide it.

If the new Italian law has established new responsibilities, new authorization principles and the willingness to operate in LEO through new infrastructures - the new Thales Alenia Space Smart Factory, inaugurated in October 2025 and the recent BROMO agreement, which was briefly mentioned above, are part of this vision - on the side of IRIDE components, some fundamental European constraints come into place. This paragraph intends to focus specifically on the European regulatory variable concerning the probable integration of AI systems along the entire end-to-end chain of IRIDE. The structure of the constellation demonstrates how the possible use of AI systems can be placed in all three segments, upstream, downstream and service segment. In Chapter 1, reference was made to how the use of AI systems and their impact in the space sector are shaping a tremendous transformation of the whole sector. The revolution imposed by new AI systems has allowed rapid development of new space missions by expanding their capabilities. An example is characterized by the new US approach: NASA is developing and deploying AI for various goals, including mission operations and planning, vehicle navigation, data communications management, anomaly detection and avoidance, human system interaction, crew and system health management, hazard detection and avoidance, and in-situ re-source utilisation (Lal & Calvin, 2022). The new fundamental role of the AI for future success is also recognized by the ESA: "Artificial intelligence is becoming vital to handle this complexity, to operate, network, coordinate and protect our space infrastructure and to get the most out of the data acquired by our scientific satellite missions" (European Space Agency, 2021).

With reference to IRIDE, the possible use of AI systems can be placed in upstream activities, where AI can perform functions related to planning, target selection and satellite monitoring, downstream, automating the process of data assembly and analysis and, finally, in the service segment sector, acting as decision-support for public policies, emergency management and for the protection of sensitive domains (security). Although not always precisely mentioned by the official documents

released, Planetek notes that thanks to the help of AI techniques, IRIDE's sub-constellations will be able to support rapid analysis for various types of emergencies: from drought to fires, from water saving in agriculture to surveillance of waste disposal and polluting discharges (Planetek Italia, n.d.).

4.1.1 EU's AI Act

To support how the issue of AI has become of fundamental importance in Europe, through Regulation (EU) 2024/1689 "AI Act", a governance framework is introduced aimed at regulating the development, marketing and use of AI in the European internal market, including for highly internationalized sectors such as space. The AI Act is structured around a risk-based approach, sorting AI systems into four broad categories, with each having associated regulatory obligations attached to them (Tricco et al., 2025). Risk categories can be broadly categorised into four groups including 'unacceptable risk' systems which will be outright prohibited, 'high-risk' systems which are allowed subject to stringent compliance obligations, 'limited risk' systems which attract transparency requirements, and 'minimal or no risk' systems that escape compliance obligations (EU Artificial Intelligence, 2024). According to Tricco et al. (2025), The EU's AI Act represents the world's most progressive and comprehensive AI regulatory framework. "AI systems" is defined as "a machine-based system that is designed to operate with varying levels of autonomy and that may exhibit adaptiveness after deployment, and that, for explicit or implicit objectives, infers, from the input it receives, how to generate outputs such as predictions, content, recommendations, or decisions that can influence physical or virtual environments" (European Parliament & Council of the European Union, 2024, Art. 3(1)). Its peculiarity is given by the fact that it is not only applied to entities that adopt and develop AI systems within the EU but, in a broader framework, also regulates the activities of organizations providing AI services that process the data of EU citizens or are otherwise importing/supplying such systems to the EU (Tricco et al., 2025). Any contravention of the standards imposed can result in significant fines, some of them increasing up to 7% of the global turnover of the organisation involved.

Specifically, the entities to which the AI Act will apply concern:

1. **Suppliers** – people or organizations that develop "General-Purpose Artificial Intelligence" (GPAI) and then bring it to market under their own name or brand (IBM, 2024). GPAI models that show significant generality such as, for example, a chatbot are defined.

2. **Users** – people or organisations that use their own AI systems or those of third parties.

3. **Importers** – persons or organizations that have their registered office outside the EU territory and that bring AI systems of a foreign person or company to the EU market (Ibid.)

As mentioned, the risk-based methodology with which the Regulation was drafted, governs AI systems based on the probability and severity of the potential damage. This implies that some applications of AI practices that are deemed to pose unacceptable risks are prohibited. In other cases, certain areas remain exempt from the regulation such as purely personal uses of AI and AI models and systems used for a scientific research or development purpose. For this reason, as already mentioned, the taxonomy adopted in four categories is useful because it tries to reduce simplistic answers.

1. **Unacceptable Risk** – AI systems falling into this category are prohibited. Examples include: *biometric categorisation system* inferring sensitive attributes, deploying *subliminal, manipulative, or deceptive techniques* to distort behaviour and impair informed decision-making, causing significant harm, *social scoring*, *assessing the risk of an individual committing criminal offenses* solely based on profiling or personality traits and *compiling facial recognition databases* by untargeted scraping of facial images from the internet or CCTV footage (European Parliament & Council of the European Union, 2024, Art. 5). Special mention for this paper regards the prohibition for *'real-time' remote biometric identification (RBI) in publicly accessible spaces for law enforcement*, except when: searching for missing persons, abduction victims, and people who have been human trafficked or sexually exploited; preventing substantial and imminent threat to life, or foreseeable terrorist attack; or identifying suspects in serious crimes (Ibid.).

Figure 13: Risk categories for AI Act (Source: Mason Hayes & Curran, 2024)

2. **High risk** –the category includes those activities listed under Annex III. If an AI system falls under the high-risk category, providers must establish: a risk management system, conduct data governance ensuring that the operations correlated will be free of errors, draw up technical documentation to demonstrate compliance and provide authorities with the information, provide a record-keeping of the events, provide instructions for use to downstream deployers, design their high risk AI system to achieve appropriate levels of accuracy, robustness and cybersecurity and provide an establishment of a quality management system to ensure compliance (Ibid.).

   Among the others, activities listed under Annex III included AI systems involved in critical infrastructure and for migration, asylum and border control management. Next paragraph will analyse how these activities are strictly related and important for IRIDE constellation.

3. **Limited risk** – These are the risks associated with the need for transparency regarding the use of AI. The AI Act introduces specific disclosure requirements to ensure that humans are informed when necessary to preserve trust. For example, when using AI systems such as chatbots, humans should be aware that they are interacting with a machine so that they can make an informed decision (European Commission, n. d.).

4. **Minimal risk** – The AI Act does not introduce rules for AI that is deemed minimal or no risk. Most AI systems currently used in the EU fall into this category. This includes applications such as AI-enabled video games or spam filters (Ibid.).

New applications of AI systems related to the space sector are no exception. The new European legislation seeks to intervene in the regulation of one of the crucial sectors of our time. One key aspect of EU law is the so-called *Brussels Effect*, in lay terms the EU's ability to set *de facto* global standards through its regulatory power (Tricco et al., 2025). As the first comprehensive regulatory framework for AI, the regulation could have the potential to serve as a pivotal point in setting new global standards in industry regulation. Although its structure tries to encompass almost all AI applications, some important exceptions are cited concerning specific cases and circumstances, some of which are of particular interest and relevance to space activities. In particular, two exceptions are considered fundamental in the structure of IRIDE: the first concerns the exceptions for "scientific

research", which states that the AI Act does not apply to AI systems, models, or their outputs which are "specifically developed and put into service for the sole purpose of scientific development" (European Parliament & Council of the European Union, 2024, Art. 2 (6)). In particular, the words "sole purpose" creates an important barrier between systems, products and technologies that have purely scientific purposes compared to typical dual-use applications. Just as the wording "government purpose" discussed in Chapter 1 has left questions about the strategic advantage of states in trying to evade the obligations imposed for military missions, at the same time, with a reverse process, new commercial organizations could try to evade the application of the obligations of the EU AI Act through new business structures (Tricco et al., 2025). The second exception concerns the "military exception". The "military exception" avoids the application of the European regulation for military "areas outside the scope of Union law" exempting "AI systems where an in so far they are placed on the market, put into service, or used with or without modification exclusively for military, defence or national security purposes, regardless of the type of entity carrying out those activities." (European Parliament & Council of the European Union, 2024, Art. 2 (3)). Again, the use of the term "exclusively" is of paramount importance, as it creates a clear demarcation for systems "placed on the market, put into service, or used" for purely defense activities and other dual-use systems. The two exemptions, as already mentioned for the case of "scientific research", could create a new scenario of possible circumvention of the European regulation by the actors involved.

4.1.2 IRIDE's AI-Enabled Systems Inside the EU's AI Act

The new European legislation provides for a new classification system also for systems that are intended "to be used as safety components in the management and operation of critical digital infrastructure […]" as high-risk systems (European Parliament & Council of the European Union, 2024, Annex III). The new Italian constellation IRIDE takes on all the characteristics to be able to fall within the category of "critical infrastructure". Its end-to-end architecture can also trigger the mechanisms of the AI Act along all possible applications of AI systems in its supply chain, making compliance an issue strictly focused on the design of the infrastructure and not on its purpose and "end use". This makes it possible to exclude that IRIDE's new AI systems may fall under a logic of exemption from the regulation relating to the two cases mentioned above. In particular, for the military case, the adverb "exclusively" seems to make the possible exemption difficult when the

capacity of the data acquired by IRIDE (acquisition, processing and final products) is intended for a heterogeneous multitude of end users.

Where could IRIDE's future AI systems fall within the risk-based classification of the EU AI Act? According to Tricco et al. (2025), it's unlikely that any space-related AI systems would be classified as unacceptable/prohibited, as that classification primarily deals with social scoring, real-time bio metric monitoring, and other systems that directly interfere with the rights of individuals. In the case of IRIDE, many systems could fall under the "High risk" profile although the classification will have to be conducted for each system and for specific system of use. Again, although the vision is consistent with the approach outlined in the work of Tricco et al., the possible field of application of dual-use technologies (AI systems) is dictated by the will of the usufructary with respect to the primordial idea of design. It follows that the difficult interpretation of the purposes of use of the various components of the IRIDE sub-constellations can on the one hand be integrated into domains that affect sensitive public functions or fundamental rights (Tricco et al., 2025), making them fall under the "high risk" category. On the other hand, in some operating segments of IRIDE (S2, S3, S5, S6) it is considered difficult how they can be included within this category, while at the same time risking being considered as "limited risk" or, if necessary, "minimal risk". The focal point will be the interpretation of how the constellation IRIDE, as a whole, will be judged as a "single system", with a central apparatus managing the various activities, or whether the various sub-constellations will be subjected to a separate judgment of the norm.

Specifically, with regard to the S8 Security segment, the document released by Pieroni (2025) is a particularly instructive case study, as it combines many of IRIDE's future activities within some areas regulated under the high risk category of the European regulation. While not explicitly mentioning topics such as AI or ML, it describes a series of typically AI-enabled capabilities such as "detection" and "classification" of objects, "tracking" and "data fusion" between different sources, as well as "route prediction" and "anomaly/activity detection" functions (Pieroni, 2025), including services explicitly oriented to sensitive contexts such as "pre-border" surveillance and "cross-border surveillance", as well as risk analysis on areas considered critical (Pieroni, 2025). In particular, the pipeline described for pre-border surveillance - based on an initial identification of hotspots through low-resolution SAR data and subsequent high-resolution monitoring with "vehicle detection and classification and activity monitoring" - shows that if AI models are adopted within these activities, it tends to be located in that area where the AI Act pays more attention for impact on public functions and rights (Tricco et al., 2025). Furthermore, the literature on the AI Act applied to space underlines

how “space-enabled” uses in areas related to borders, security and surveillance have a higher probability of falling into more stringent regulatory categories (Ibid.). The data listed describe a scenario in which it is considered very likely that S8 activities could fall under “high risk”, although the ambiguity of the dual-use theme remains a complicated junction even for IRIDE.

Finally, from a strategic-industrial point of view, the dual-use nature of the constellation, related to the obligations imposed by the AI Act, could translate into a potential short-term competitive disadvantage for the companies and states involved, compared to non-EU players. The possible classification of a given AI system within a risk category, especially in the “high risk” case, would entail articulated obligations as described above. The issue is not strictly legal but concerns the ability of European programs to maintain a competitive pace compared to international competitors. Although the European regulation has established ethical principles of governance and responsible use of AI, it may lead to a slow in innovation and deter new entrants into the space industry (Veale et al., 2023). In addition, the process adopted by the AI Act adopts an approach that involves not only European actors but also non-EU entities when involved in the provision of systems and services used within the European Union. This could create a climate of discouragement and a competitive advantage for those who operate exclusively from Europe. On the other hand, European companies developing new technologies may decide to migrate their services to foreign countries, in order to circumvent the obligations imposed by European legislation. The European Commission’s proposal to postpone the application of the stricter rules for “high-risk AI systems” until 2027 appears to support this vision, justifying the choice with the need to reduce the bureaucratic burden and improve the competitiveness of the European context (Reuters, 2025).

4.2 IRIDE's Potential Risks Under the GDPR

Through the data value chain of EO constellations (more generally infrastructures), the acquisition and initial processing of data is acquired by *in-situ* sensors directly on satellites. The development of sensor technologies such as SAR and VHR has amplified, over time, the speed of the end operator to direct access to the acquired data. The democratization of access to and use of space data through satellite imagery free open-source and technological developments in data infrastructure are producing a culture of shared and increasingly open information available to both public and private industry (Scott, 2016). In this context, AI systems act as a value multiplier in the chain: as seen above, thanks to the integration of new AI systems, the various data processing phases are largely automated and speeded up. In other words, AI is employed to process Big Data to provide fast and precise analysis (Tricco et al., 2025) and their application in the space field does not seem to have boundaries of use in the future.

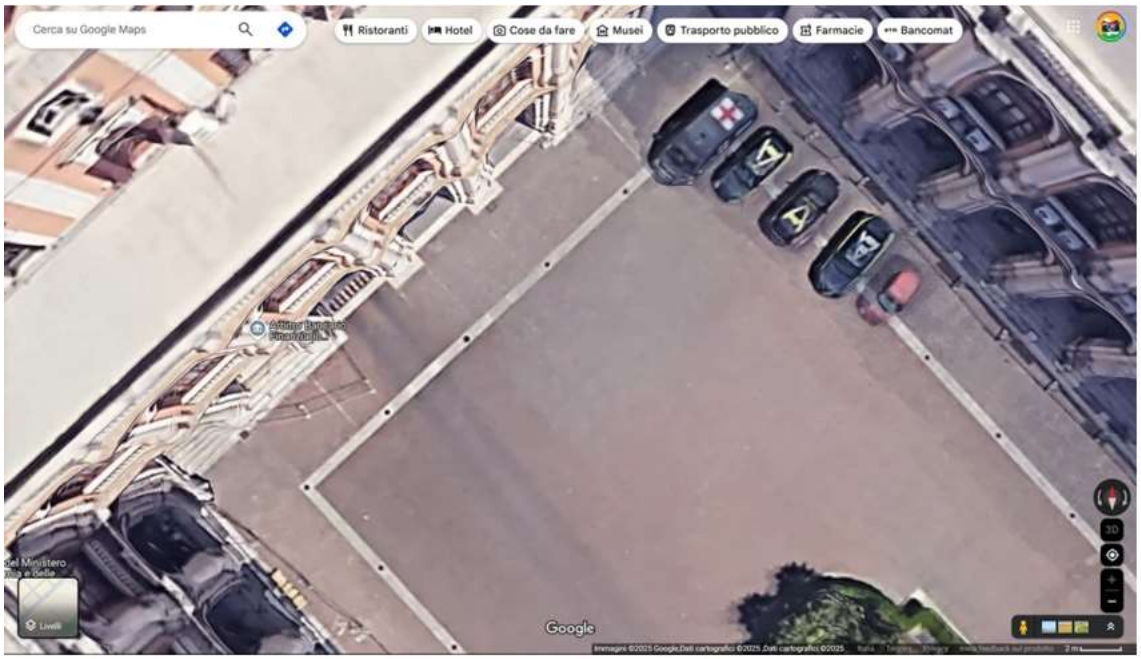

Figure 14: Corte del Ministero dell'Economia e delle Finanze. Google Maps. (Source: Izzo & Campanile, 2025)

As of today, the sharpest image acquired by EO satellites has a resolution of 15/30 cm, but there is a tendency in the industry to push for the resolution restrictions threshold to be lowered to 10 cm (Santos & Rapp, 2019). Figure 14 depicts a Google Maps' screenshot showing an external environment of the Ministry of Economy and Finance (MEF) facility, in which it is possible to accurately detect three different cars of the "Guardia di Finanza" (Italian Tax Police), a military

ambulance and sharp details of the surrounding environment (Izzo & Campanile, 2025). The images available on Google Maps are a combination of a fusion of satellite images (and aerial images) from institutional and commercial providers, such as Copernicus, Maxar, Airbus and others (Ibid.), making the image "imperfect" but not devoid of relevant details.

The evolution of the space sector amplifies the amount of data acquired day by day, increasing the risks of acquiring "personal data" and sharing it. The risk of sharing sensitive data is also multiplied by the legislative nature behind the data acquired: principles of "freedom of access" and "freedom of use" were introduced in Article 1 of the OST which establishes freedom in the exploration and use of outer space, based on which States are entitled to conduct EO activities without territory restrictions (Santos & Rapp, 2019). It also includes the obligation to cooperate and the principle of "non-appropriation" which prevents a state from making a claim or exercising jurisdiction over all or part of outer space (even if the provisions of Article II relate mostly to celestial bodies rather than to data produced by satellites) (Ibid.). Moreover, States are also responsible for the activities of commercial actors, as Article VI states. But the current legal space framework highlights the lack of an international treaty – or other instrument of a comparable legislative nature – on the management of the protection of personal privacy, although the right to privacy is recognised and protected by international human rights law and European human rights law,3 as well as case-law interpretations (Von der Dunk, 2009). The lack of a regulatory basis also derives from the fundamental value acquired by such data in the global economic context, alternatively creating a series of "regulatory layers" on two classes: international and national (Izzo & Campanile, 2025). If on the international front, in addition to the aforementioned OST, acts of conventional law such as the principles promulgated by the UN in 1986 on Remote Sensing, at the national level regulations have been implemented that provide for future obligations assumed at international level (Ibid.).

4.2.1 European Data Regulation: GDPR

The EU Regulation 2016/679 General Data Protection Regulation (GDPR) has introduced a new European legal framework for the regulation and protection of personal data and their free movement within the European Union. It is important to underline that although the Regulation regulates the obligation for data management for all companies involved, data are described as those that lead back or can indirectly lead back to natural and non-legal persons. Regarding the space data, Article 3 (1) states that any entity that directly or indirectly collects or processes data of EU residents is subject to the GDPR, even if taken from a satellite under the jurisdiction and control of a non-EU country (European Parliament and Council of the European Union, 2016, Article 3 (1)). The principle of "accountability" introduced by art. 5 provides that the data controller "must guarantee and always be able to demonstrate compliance with the principles of the Regulation" as well as "that he has implemented the measures deemed appropriate by the Data Controller himself" (European Parliament and Council of the European Union, 2016, Article 5 (1)).

In the spatial context of Big data, it is important to outline what is understood in the Regulation as "personal data". Including images, GDPR regulates the use of multiple data formats linked to the treatment of Personal Data defined as "*any information relating to an identified or identifiable natural person*" (European Parliament and Council of the European Union, 2016, Article 4 (1)).

1. **"Any information"** refers to all the possible information of the individual – objective information, subjective information, opinions or assessments (Santos & Rapp, 2019) – and regarding the "content" of the information, they are included data which could give any sort of information.

2. **"Relating to"** refers to those cases where it's related to the individual when it covers information *about* that individual and referring to satellites' images, when the images concerns objects rather than individuals, they can still be *indirectly* related to individuals due to the Article 29 of "Working Party Opinion" (Ibid.).

3. **"Identified or Identifiable natural persons"**, it refers to individuals who among a group of persons can be distinguished or singled-out from all the other members of a

group, so can be identifiable when, although the person has not been identified yet, it is possible to do it (Ibid.).

Having therefore specifically analyzed the regulatory details of the GDPR relating to "Personal Data", it is therefore possible to classify data (including satellite data) through the dichotomy "personal or non-personal data". As Figure 14 shows, in almost all cases of acquisition of satellites images both types of data are present. If art. 3 of Regulation (EU) 2018/1807 on the free flow of non-personal data identifies the same as "data other than personal data defined in Article 4 (1) of Regulation (EU) 2016/679 (GDPR)" (European Parliament and Council of the European Union, 2018, art. 3 (1)), in the case that a dataset (satellite image) contains both types of data, the Regulation is applied for "the part of the set containing non-personal data" and, specifies that "where personal and non-personal data within a data set are inextricably linked, this Regulation shall be without prejudice to the application of Regulation (EU) 2016/679." (European Parliament and Council of the European Union, 2018, art. 2 (2)). So, if the data is "inextricably linked" the GDPR is applied to the entire dataset. In reality, this context is difficult to apply to the context of remote sensing carried out by means of satellites (Izzo & Campanile, 2025).

Therefore, to understand the real application of the GDPR in relation to spatial data, it is not important the origin of the data, i.e. whether the data comes from a satellite, but, rather, whether it contains, or if it can become, personal data. This step is of fundamental importance related to the evolution of the quality of satellite images. As highlighted by Santos & Rapp (2019), it is not currently possible to directly identify an individual´s face using today's satellites. The resolution does not suffice to depict optical characteristics of a person's features. Satellite imaging consists of coarse resolutions that do not typically allow for recognition of individual's faces, and they tend to image structures and features that are themselves publicly viewable (Santos & Rapp, 2019). Today's ability, or inability, to identify directly could change in the short term. In addition, through the adoption of combined analysis processes of images and other external sources, it is possible to produce consistent outputs that make the identification of an individual plausible. A single satellite frame can thus be converted into a real profiling of an individual. Identifiability is not, therefore, a static attribute but evolves over time thanks to the aggregation of auxiliary data and technological evolution during the life cycle of the data (Ibid.).

That said, there is no clear risk at present that space companies will have to deal with and comply with GDPR dispositions for their data collection from space, however, it is a problem that

will be increasingly present in the coming years (Tricco et al., 2025). Possible new scenarios could also open up in relation to the application of AI-enabled systems in the field of automated decisions and profiling. Art. 22 of the GDPR states that "The data subject has the right not to be subject to a decision based solely on automated processing, including profiling, which produces legal effects concerning him or her or which similarly significantly affects him" (European Parliament and Council of the European Union, 2016, Article 22 (1)). As a result, satellites equipped with Very High-Resolution (VHR) cameras and an AI analytics software that autonomously discharges or sends data down to Earth could be impacted by it (Tricco et al., 2025). Although the "European Data Protection Board" (EDPB) (2018) has provided interpretative guidelines on automated decisions and possible profiling, regarding EO applications not only can the satellite autonomously decide about the acquisition of images that may concern an individual, but it becomes even more crucial in the context in which analytical products can be implemented downstream in strategic contexts such as surveillance.

4.2.2 GDPR Applicability to IRIDE and Differences from Copernicus

The technical and operational characteristics of IRIDE make it a perfectly applicable case study for the provisions of the GDPR described above and the associated risks between EO systems and the protection of personal data. It has been seen how potential images or quantifiable datasets such as the acquisition of non-personal data can include within them, through an indirect deduction, data relating to identifiable individuals (personal data). In addition, the enrichment with auxiliary data and the growing inferential capacity of new analysis tools can "transform" the acquired data, making the identification and possible profiling of individuals clearer. Since IRIDE is an end-to-end system, the overall functionality emerges from the entire processing of the data, exposing it to greater exposure that certain products may fall under the notion of personal data and that obligations may thus arise under art. 5 of the GDPR. The SeBS model, which follows the lines set out in the "Space Strategy for Europe" (2016), will allow a wide public access and the opportunity to analyse and use information obtained from satellites. Orbital Insight, SpaceKnow, Descartes Labs, Exogenesis, Remote Sensing Metrics, OmniEarth, DataKind are examples of analytic support companies offering insights or intelligence that enhance data analysis (Santos & Rapp, 2019), making it possible, even in

the case of IRIDE, to transform the data obtained into potential personal data that violates the privacy of individuals.

Although the new Italian constellation has taken inspiration from the already active European Copernicus constellation, the differences in governance pose substantial legal differences in the scope of application of the GDPR and other European regulatory instruments. The main difference lies in the fact that Copernicus is part of an EU sectoral regulatory framework that regulates its governance but, above all, data access and dissemination is regulated. In particular, a mechanism is envisaged that expressly considers the balance between data availability and protection of fundamental rights, including the protection of personal data and privacy, through specific provisions on the management of potential conflicts between dissemination and rights (Izzo & Campanile, 2025). This system recognises, through the specific Regulation (EU) 2021/696, the need for mitigations in the presence of high-impact outputs or use scenarios.

As in the case of IRIDE, for initiatives that are mainly developed in a national dimension, the dynamic tends to be different. For data collected by national space entities constituted by the Member States of the European Union, Directive 2019/1024 and the INSPIRE Directive (Ibid.) are applicable, regarding data dissemination activities only. About EO data collected and disseminated by commercial operators, however, the applicable discipline is entirely outlined by the individual States. At the date of writing, none of the regulatory acts currently in force on satellite remote sensing contains a reference to the GDPR in relation to the dissemination and exploitation of the related data, nor does it openly consider the hypothesis that the same may or may not constitute personal data (Ibid.).

The possible adoption of AI-enabled systems in IRIDE's sub-constellations may create further ambiguities in both the upstream and downstream dimensions. On the one hand, the automation of the selection of the acquired images could collide with Article 22 of the GDPR. On the other hand, datasets that do not include personal data today can be developed in the future through the development of new related technologies.

4.3 The PNRR Paradox: Ambiguities in the Dual-Use Potential Application of IRIDE

As seen in chapter 2, the idea of a new Italian constellation of satellites capable of guaranteeing new EO services was born in 2021. The international crisis caused by the Covid-19 pandemic has led to the creation of an "unprecedent recovery plan", the so-called "Next Generation EU", with which an attempt is being made (the plan will end in 2027) to restart the economies of the 27 member states, severely tested by the catastrophic impacts of the pandemic. The Next Generation EU is the instrument with which the European Commission is authorised to borrow funds on behalf of the Union on the capital markets up to the amount of €750 billion (in 2018 prices). All member states ratified the own resources decision by 31 May 2021, thereby empowering the Commission to borrow the money (Council of the European Union, n.d.). The plan is divided into seven different programmes established through the measure of loans and grants from the Union. Among these, the centrepiece of Next Generation EU, "Recovery and Resilience Facility" (RFF), has the goal "to make the economies and societies of the 27 more sustainable, resilient and prepared for the green and digital transitions, in line with the EU's priorities" and "to address the challenges identified in country-specific recommendations under the European Semester framework of economic and social policy coordination" (European Commission, n.d.). In other words, the RFF consists of a growth-oriented system of reforms and investments, increasing the resilience of the 27 and being the cornerstone in leading the various states towards European standards on green and digital transition issues. The framework of reforms was formalized through the adoption of Regulation (EU) 2021/421, which contains the institutional indications that provide for the allocation of 37% of total expenditure to "green" objectives and at least 20% to the digital transition (European Parliament and Council of the European Union, 2021).

Within this scenario, on 22 December 2021 ESA and the Italy's Minister for Technological Innovation and Digital Transformation signed the agreement which official started the programme IRIDE. The total investment of €1.07 billion, with €797 million drawn from PNRR funds and the remaining €273 million from Italy's National Complementary Fund (NCP), a complementary financial plan that integrates and enhances the contents of the PNRR. It is important to underline how the new financial system was crucial for the purposes of the IRIDE project. It is also important to understand the destination of Italian funds to comply with the targets imposed by the Next Generation EU. In its initial configuration, the PNRR was divided into 6 main missions: Digitalization, Green Transition, Mobility, Education, Inclusion, Health for a total of over 200 billion euros. In chapter 2, the four key projects within Mission 1 "M1" (Digitalization, innovation, competitiveness, culture and

tourism) – Component 2 "C2" (Digitization, innovation and competitiveness in the production system) – Investment 4 have been listed. From the official data published on the website of the Ministry of Enterprise and Made in Italy (MIMIT), investment 4 "aims to develop satellite connections in view of the digital and green transition and contribute to the development of the space sector. The investment also aims to enable services such as secure communications and monitoring infrastructures for various sectors of the economy and includes to this end both upstream (launch services, production and management of satellites and infrastructure) and downstream (generation of enabled products and services) (Ministry of Enterprise and Made in Italy, n.d.). The breakdown of official expenses dedicated to the IRIDE project can be seen in Figure 15, "Earth Observation".

Investimento	Fonti di finanziamento	2022	2023	2024	2025	2026	IMPORTO TOTALE
Osservazione della Terra	PNRR	52.000.000,00	140.000.000,00	185.000.000,00	280.000.000,00	140.000.000,00	797.000.000,00
	Fondo Complementare	46.000.000,00		35.000.000,00	70.000.000,00	122.000.000,00	273.000.000,00
TOTALE		98.000.000,00	140.000.000,00	220.000.000,00	350.000.000,00	262.000.000,00	1.070.000.000,00
Space Factory programma di Accesso allo Spazio (Sistemi di trasporto spaziale)	PNRR	4.000.000,00	10.000.000,00	40.000.000,00	10.000.000,00		64.000.000,00
	Fondo complementare	6.000.000,00	6.000.000,00	5.000.000,00	10.000.000,00	9.000.000,00	36.000.000,00
	Fondi PCM	50.500.000,00	28.000.000,00	17.000.000,00	16.000.000,00	6.000.000,00	117.500.000,00
TOTALE		60.500.000,00	44.000.000,00	62.000.000,00	36.000.000,00	15.000.000,00	217.500.000,00
IMPORTO TOTALE		158.500.000,00	184.000.000,00	282.000.000,00	386.000.000,00	277.000.000,00	1.287.500.000,00

Figure 15: Financial Investment for the sub-programme Earth Observation and Space Factory. (Source: Presidenza del Consiglio dei Ministri, 2022).

In the minutes of the 15th session of the Interministerial Committee for Space and Aerospace Policies (COMINT) of 1 December 2021, in order to relaunch the Italian role in the European space context, the then Minister Colao identified the EO sector as the key sector to focus on as "(i) there are possibilities for the inclusion of private funding, (ii) it would result in a series of important services ("downstream") of both an institutional and commercial nature, (iii) it would make it possible to consolidate and strengthen Italian leadership and skills in this area" (Presidency of the Council of Ministers, 2022). There is no mention of a possible strategic use in areas such as defense or in the military. The MIMIT itself excludes that the entire M1C2-4 investment may have "objectives or military or defense implications" (Ministry of Enterprise and Made in Italy, n.d.). The EU's primary system itself places a structural limit on the financing of expenditure attributable to "operations having military or defence implications" charged to the EU budget. In the design and financing phase, therefore, IRIDE was not considered a system capable of having military or defense implications. It is possible to define the program *ex ante* as a "civil-first" investment. The previous analysis of

possible activities within IRIDE's S8 operating segment highlights a real ambiguity in this regard. Yet, in the same minutes, the Minister for Defense Lorenzo Guerini, outlined "the urgent need to understand, within the framework of the PNRR programs, the projects proposed by the Ministry, in particular for the SATCOM line of action the SICRAL 3 program, otherwise the need to realign Defense programming by drawing resources from other programs" (Presidency of the Council of Ministers, 2022), receiving reassurances from the President of COMINT on an informal positive opinion received at EU level. It is therefore clear that the dual-use nature of the SATCOM program raised questions about the nature of the PNRR funds and its possible use for the financing of the SICRAL 3 program (Italian System for Confidential Communications and Alarms), part of the current Italian satellite system for military communications.

The need to converge post-pandemic European funds in the defense sector of the various European states has accelerated rapidly due to the geopolitical change described above. In May 2025, the European Commission permitted Poland to repurpose nearly €6 billion in post-COVID funds to finance defence projects (Tidey, 2025) as defence sector became a key priority for the country after the Russia's full-scale invasion of Ukraine. The possibility of converting European funds into the defence sector has in fact broadened the initial notion of "resilience", projecting it towards a security dimension. The proposal of a possible mirror project such as IRIDE would not cause the same ambiguities in justifying the nature of the funds. However, this change does not retroactively rewrite the origin of the 2021 PNRR targets. In this diachronic context, the dual-use ambiguity of IRIDE takes on a central value: again, it is not enough to claim the original civilian purpose of the project, nor to assume that it has a prevalence of military use, but it is necessary to highlight how, *de facto*, the distance between "civil-first" and "military-first" projects is today an issue that depends less on the formal label of the program and more on the actual use cases.

Conclusions

The intrinsic dual-use nature of modern satellite systems tends to be configured no longer as an isolated case but as a typical condition. The difficulty in demarcating the boundary between civil and military applications makes it necessary to use analysis tools that go beyond the typical scientific scenario of the technologies currently used in outer space. Thanks to the progress of scientific research, the involvement of new players in the market and the possibility of profitable investments, space is configured as one of the most attentive strategic domains of our time. In this perspective, AI acts as a multiplier of the strategic value of the space domain, managing to drastically reduce the uptime of space systems, making it perfectly integral in the entire value chain of current satellite constellations. Technological-industrial competition opens up new configurations of space operations conducted by special military commands, creating an increasingly close link with the security and defense sectors. The emergence of new terrestrial conflicts has accentuated this link: the availability and governance of space infrastructures are converted into a strategic advantage in the military field. At the same time, the common difficulty of states (mainly European but not only) in justifying new military investments to public opinion finds a perfect match in the dual-use nature of satellite constellations.

Inserted in the scenario just described, from a qualitative point of view, this paper has tried to develop some of the ambiguities, possible advantages and disadvantages related to the new Italian constellation IRIDE. From the institutional documents released, the Italian EO program was born with a vocation of public value, with a push towards open-source accessibility models inspired by previous European experiences. The inclusion of the S8 Security segment combined with the concept of the end-to-end constellation integrates it, in fact, into the national security ecosystem. This places IRIDE within a broader analysis scenario. On this level, three main possible ambiguities relating to the current European regulatory scenario and the dual-use nature of the work were analyzed.

The first refers to the potential use of AI-enabled systems of the constellation and their classification within the European AI-Act Regulation. The technical characteristics of IRIDE combined with its dual-use nature include it together with other systems that the European Regulation defines as “critical infrastructure”; consequently, the possible adoption of AI systems along the entire value chain could make it fall within the “high risk” category of the risk-based classification system proposed by the AI-Act. This would entail high compliance obligations, which, on the one hand, would provide greater security from an ethical point of view regarding the governance and processing

of data processed by AI systems. On the other hand, in this precise field of analysis, the dual-use nature of IRIDE could lead to a strategic disadvantage. Historically, high compliance obligations discourage companies from investing in infrastructures of this type, being able to migrate their services to governance systems that guarantee greater freedom of management and use.

Secondly, the rapid evolution of the analytical capabilities of the data acquired by satellites could transform data currently classified as "non-personal" into information that could potentially be traced – directly or indirectly – to individuals. The process could be amplified by the inferential ability to link acquired data to additional auxiliary sources. While the risk that space companies may have to submit to the obligations imposed by the (EU) GDPR Regulation seems, to date, not to be significant, new scenarios could lead to a revolution in the issue. Again, the adoption of *in-situ* AI systems could collide with Article 22 of the Regulation, on automated decisions and profiling. Finally, the difference in governance of European/national space activities involves different obligations in compliance with the GDPR, creating ambiguity in the yardstick of application of the same Regulation.

The third and last is the so-called "PNRR paradox". At the end of 2021, thanks to new extraordinary European funding measures in response to the severe covid-19 pandemic crisis, the IRIDE project was able to take advantage of public funds mainly oriented towards the digital and green transition. On a diachronic level, the dual-use nature of the constellation reaffirms the delicate balance between civil/military applications and raises questions about the lawfulness, purposes and methods of use of PNRR funds. Although the emergence of new crisis scenarios in recent years has seen the possibility of using funds from the Next Generation EU programme for the defence and security sectors, the initial difficulty of the main institutions in recognising IRIDE as a dual-use system reaffirms the permanence of a delicate conceptual and political "limbo" for infrastructures operating along a "grey zone".

Since IRIDE is a project still evolving and not completed, the present paper has structural limitations due to the difficulty in fully observing all the completed components of the constellation. The work, therefore, will need future integrations when the constellation will reach full operation, through empirical data (analysis of the data obtained) and with possible interviews of the main protagonists involved.

In conclusion, despite the ambiguities analyzed, the thesis argues that IRIDE represents a fundamental step for the increase of Italian capabilities in the space domain. Its effectiveness will be determined by the ability of the constellation to correctly fulfil all the operational segments architected. At the same time, Italy's positioning within the international framework of the *new space*

order and its role within the EU will be decisive in enhancing IRIDE not only as a technological asset but as a strategic infrastructure capable of strengthening the country's resilience.

Appendix A: Technical Specifications of IRIDE Sub-Constellations

The technical specifications of the six sub-constellations of IRIDE (HEO, EAGLET-2, NIMBUS-VHR, NIMBUS-SAR, NOX and PLATINO-HYP) are listed below in order to provide a technical framework for a better understanding of the operations, the technologies adopted and the various orbits of the upstream segment of IRIDE. The following information was derived from the work of Cadau et al (2024).

1. **Hawk for Earth Observation (HEO)**: developed by Argotec, the first batch of the sub-constellation includes 10 microsatellites inserted in a Sun-synchronous orbit (SSO) at about 550 ± 50 km altitude. On board, the satellites will be equipped with a pushroom multispectral optical instrument, in more common terms it is a sensor that "scans" the surface along the direction of motion of the satellite. The sensor observes 8 spectral bands, including a panchromatic channel, with a spectral range ranging approximately from 490 to 892 nm (therefore in the visible and near infrared) (Ibid.). The reported ground resolution (SSD) ranges from 2.7 to 5.4 meters, with an observed crawl (swath) of about 10.9 km. From the point of view of the products, as specified in the figure 13, HEO systematically generates basic products that follow a "level" logic: Level-0 (raw data), Level-1B (TOA-corrected radiance, i.e. at the top of the atmosphere, in sensor geometry) and Level-1C (TOA reflectance in map geometry) (Ibid.).

Product	Description	Size [km²]
Level-0	Raw Payload Data + Navigation Data	10.9 x 10.9
Level-1B	TOA corrected Radiance in Sensor Geometry	10.9 x 10.9
Level-1C	TOA Reflectance in Cartographic Geometry	~10.9 x 10.9

Figure 16: HEO different levels. (Source: Cadau et al., 2024)

2. **EAGLET-2**: developed by the company OHB, it consists of 12 microsatellites in SSO orbit at 525 km from the earth, with an RGB imaging instrument (therefore three bands in the visible) that guarantees 2 meters of resolution on the ground and a swath of 18.3 km. An important point is that, in addition to the optical sensor, each satellite is also

Product	Description	Size [km²]
Level-0	Raw Payload Data + Navigation Data	N/A
Level-1A	TOA raw Radiance in Sensor Geometry	10.5 x 10.5
Level-1B	TOA corrected Radiance in Sensor Geometry	10.5 x 10.5
Level-1C	TOA Reflectance in Cartographic Geometry	10.5 x 10.5

Figure 17: EAGLET-2 different levels. (Source: Cadau et al., 2024)

equipped with an AIS instrument, a receiver that allows you to acquire messages transmitted by ships and thus support the tracking of maritime traffic. As shown in figure 14, the optical EO products of EAGLET 2 are organized into Level-0, Level-1A, Level-1B and Level-1C (where the main difference is between raw radiance, corrected radiance and reflectance in cartographic geometry), while the AIS output has a reference radius of about 2700 km (Ibid.).

3. **NIMBUS-VHR**: as already seen above, developed by Thales Alenia Space Italia, it refers to a VHR (Very High Resolution) optical satellite, defined as "agile", i.e. capable of performing more flexible pointing maneuvers to capture scenes with greater versatility. It is placed in SSO orbit at 460 ± 15 km. The indicated swath is 10.5 km. From a spectral point of view, the sensor has 4 VNIR bands (visible and near infrared) with a 4 m SSD on the ground, and a panchromatic channel with an SSD of about 0.9 m, therefore much more detailed. Here too, as shown in figure 15, the products follow the Level-0, Level-1A, Level-1B, Level-1C chain, which corresponds to the transformation from raw data to a radiometrically correct and then georeferenced/cartographic product (Ibidem).

Product	Description	Size [km²]
Level-0	Raw Payload Data + Navigation Data	N/A
Level-1A	TOA raw Radiance in Sensor Geometry	10.5 x 10.5
Level-1B	TOA corrected Radiance in Sensor Geometry	10.5 x 10.5
Level-1C	TOA Reflectance in Cartographic Geometry	10.5 x 10.5

Figure 18: NIMBUS-VHR different levels. (Source: Cadau et al., 2024)

4. **NIMBUS-SAR**: associated with the NIMBUS platform, in this case it does not have an optical sensor, but SAR radar. It includes 6 satellites in medium inclination orbit (MIO) with an inclination of 49° and an altitude of about 560 km. This orbital choice helps, among other things, to better measure the component of ground displacement in a north-south direction. The SAR instrument operates in the X-band with a transmission band up to 1000 MHz, transmitting and receiving in vertical polarization (VV) (Figure 16). Typical SAR operating modes are envisaged: Spotlight, Stripmap and ScanSAR (Figure 17), which represent different trade-offs between detail and breadth of the observed scene (Ibid.).

NIMBUS SAR Constellation	
Orbit:	Inclined orbit from 44° to 49°
Radar:	X-band, single pol. (VV)
Swath / Observed area:	2.5km (spot); 23km (strip); 100km (scan)
Ground resolution	From 0.5m to 17m depending on the operating mode

Figure 19: NIMBUS-SAR specifics. (Source: GEOmedia, 2023)

Mode	Swath width	Ground Resolution
Spotlight	2.5 km	0.5 m
Stripmap	23 km	3 m
ScanSAR	100 km	17 m

Figure 20: NIMBUS-SAR different modes. (Soruce: Cadau et al., 2024)

5. **NOX**: developed by D-Orbit, it is also based on an X-band SAR sensor with VV polarization. The main difference of the constellation lies in the orbit in which it operates, SSO at 515 km. An additional operational detail is that NOX can capture "continuously" for more than 180 seconds, with the capability, therefore, to capture extended scenes or capture sequences. NOX also operates in Spotlight, Stripmap, and ScanSAR (Figure 18), but with slightly different performance values: Spotlight with 10 km swath and 1 m resolution, Stripmap with 30 km swath and 1.6 m resolution, ScanSAR with swath between 50 and 80 km and resolution between 4.8 and 6.4 m.

Mode	Swath width [km]	Ground Resolution [m]
Spotlight	10 km	1 m
Stripmap	30 km	1.6 m
ScanSAR	50 -80 km	4,8 – 6,4 m

Figure 21: NOX different modes. (Source: Cadau et al., 2024)

6. **PLATINO-HYPERSPECTRAL**: developed by SITAEL, it includes four hyperspectral satellites with the aim of ensuring continuity with the Italian PRISMA mission and compatibility with the ESA CHIME mission. The four satellites are distributed "equally spaced" along a reference SSO orbit at 519 km, in order to improve overall time coverage. The hyperspectral camera has a continuous spectral coverage from 400 nm to 2500 nm, so from visible to near-infrared and shortwave infrared. This is a crucial point: compared to multispectrals, the hyperspectral sensor allows you to measure many more wavelengths, thus being much better suited to distinguish materials and chemical-physical properties of the surface. The swath is indicated in about 21 km and the resolution on the ground varies from 5 to 30 meters (depending on the product and configuration). Figure 19 lists the various product levels: Level-1 (TOA corrected radiance), Level-2B/2C/2D as "BOA" (Bottom Of Atmosphere) products, i.e. corrected by atmospheric effects, distinguishing between radiance and reflectance and between sensor geometry and cartographic geometry. Geocoding is applied during L2 processing only after atmospheric correction (first the signal is "cleaned" and then the data is reported in the cartographic geometry) (Ibid.).

Product	Description	Size [km²]
Level-0	Raw Payload Data + Navigation Data	N/A
Level-1	TOA corrected Radiance in Sensor Geometry	21 x 21
Level-2B	BOA spectral Radiance in Sensor Geometry	21 x 21
Level-2C	BOA spectral Reflectance in Sensor Geometry	21 x 21
Level-2D	BOA spectral Reflectance in Cartographic Geometry	21 x 21

Figure 22: PLATINO levels. (Source: Cadau et al., 2024)

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